# PROFESSIONAL PAPERS

ON

# INDIAN ENGINEERING.

VOL. VII.—1870.

EDITED BY

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JAMES JOHNSTON, SUPERINTENDENT.

## PREFACE TO No. 29 AND VOL. VII.

WITH this last number of Vol. VII., I close the present series of the "Professional Papers." After 8 years' residence at this College, I am about to apply for Furlough to England, and I cannot, of course, pledge my successor to carry on a work on which I have expended an amount of labor, time and trouble which he may not be able to afford, more especially as the College work is steadily increasing year by year.

I sincerely hope it may be practicable at some future time to commence a new series of these Papers, either under my own Editorship or that of some future Principal. There can be no lack of matter while so many great works are in progress in various parts of the country, and the advantages of such a collection of Papers, weeded of extraneous official matter, and in not too bulky a form, are too great to be questioned. The present occasion, however, seems to be appropriate for closing the First Series, now amounting to 7 Volumes, containing 294 separate Papers, and costing 120 Rs.

The re-print of Vol. I. has been completed, and it is now available at the reduced price of 12 Rs. The re-print of Vol. II. will shortly be put in hand. Vols. III., IV., V., VI. are still available at 18 Rs. a copy, and Vol. VII. at 14 Rs.; also most of the Quarterly Nos. and separate Papers, so that those who do not care to purchase the whole series can procure such papers as they may

desire to have, at a moderate expense. An Index to the whole 7 Volumes will be prepared directly, and sold separately.

In the Introductory Preface which I wrote seven years ago with the First Number I described what I proposed to myself in starting these Papers and the field that lay before us in the large number of Engineering subjects that awaited treatment. In looking back to that Preface, the promises made in it seem to me to have been very fairly carried out. I have received many more original Papers than I could have reasonably hoped for in a country where every man is overwhelmed with Office work—and the selection from Official papers has been, I think, carefully made. Many important works have been here described—many subjects of great practical interest have been treated of—many theoretical questions have been ably discussed.

There still, however, remains much to be done under these last two heads, and it may be useful if I again direct attention to such special questions of Indian Engineering as may be regarded as still awaiting discussion and solution.

In *Railways*,—the questions of the narrow gauge and the economy of different gradients seem to be at present the most pressing. But there are other questions which I hope to see discussed in some future series of these Papers, such, for instance, as a really satisfactory Wrought Iron Way. Take again the present arrangements for Passenger traffic. Why cannot they be simplified and improved? Why should every passenger have to buy his ticket just before the train starts? Why should he not buy it at the nearest town a week beforehand if he likes? Could not there be some ar-

rangement (on the principle of postage stamps) for one ticket to cover all journeys under 50 miles, another under 200 miles, and so on; this would prevent much fraud amongst native travellers, which ultimately of course injures the railway. Then for the European traveller—why should every man's luggage require to be weighed? If it were counted by the piece, much time and temper would be saved. Most people agree that the present forms of carriages for all three classes of travellers are very far from perfect, but it is not so easy to devise remedies.

As to *Roads*, I believe their importance is more and more increased by the introduction of Railways, and I have more than once urged the great importance of their extension in all parts of the country—a subject which I do not think is at all sufficiently appreciated. Yet the Famine in Orissa, and that still more recently in Rajpootana and Rohilcund, should have showed us the urgency of the question, which I believe to be far more pressing than Irrigation. The great difficulty about Roads appears to be the enormous cost of the Metalling in so many parts of the country. And in that view I would seriously urge the adoption of stone or iron tramways, or of horse railways, or of a combination of the tram and rail for a cattle-power line, such as has been found successful in America. These have never been properly tried yet, and it is high time that they should be; I hope to obtain full information on this subject before long, with a view of bringing it specially to the notice of Government.

Scarcely inferior in importance to the above is the subject of *Navigable Canals*, which have only lately engaged much attention in Upper India, and in which scarcely anything has been actually

*done* as yet. In a country where economy of transport is so much more important than time, and where the (necessarily) high cost of railway carriage makes it most unsuitable for such articles as grain or minerals, it appears a subject of most pressing importance, which is apt to be lost sight of in the claims on our attention made by

*Irrigation.*—I have more than once said that, without doubting the importance of this subject, I do not believe it to be the *panacea* that is too often supposed. I would far rather see facilities of transport largely multiplied. I do not believe that it would be an unmixed benefit to cover the face of the country with irrigation channels, by which agricultural produce would be indefinitely increased and at as small an expenditure of labor as possible. Who is to consume all this produce, unless we give facilities of transport to enable it to be exported? The population might doubtless keep pace with the extension of irrigation in time, but the first results of irrigation in many districts seem rather to decrease the population by increasing sickness. Doubtless this is preventible to a great extent by drainage and other sanitary precautions, but the cost of these, when fully carried out, will go far to diminish the profits of irrigation, and when, as in the case of rice (in Upper India at least), the irrigation of a certain crop is invariably attended by an increase of disease, it would seem only rational to prohibit it and bring it from elsewhere, where it can be raised without danger to health and life.*

In the construction of *Buildings* the more extended use of Concrete—and of Artificial Stone—and the improvement of Cements, have been very important subjects of discussion. Several valuable

* See Irrigation Tract, No. I., published at Roorkee, on the Cultivation of Rice in Portugal.

papers on these subjects have appeared in this Series, but no very definite results have yet been obtained. I have also several times advocated the improvement of our building pottery. Very great improvement has been effected in bricks, though Hoffmann's kilns have not yet passed beyond the experimental stage, but little or nothing has yet been done in the manufacture of ornamental pottery, which is a great desideratum in this country.

The Barrack question is still in an unsettled state; and the whole question of Architecture for Anglo-Indian dwellings is as open as ever to the clever young architect to solve. Look at Delhi, for example, where the Delhi Institute in the Classical style faces a Gothic clock tower, and both under the shadow of such a building as the Jumma Musjid! Similar incongruities abound everywhere, and while we cover the country with hideous bungalows and unsightly public buildings, we have actually set up more than one School of Art to teach the natives, from whom, I fear, we have yet very much to learn.

In conclusion, I beg sincerely to thank the various contributors to whom the Engineering profession owes these Papers. Mine has been the modest task of selecting, arranging, and occasionally altering them for the Press; but I am proud to have been the means of enlisting so many able writers, and of presenting to Government and the public so valuable a mass of professional information.

J. G. M.

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*** I take this opportunity of announcing that, by the close of this year, the 2nd Edition of Vol. II. of my "Treatise on Civil Engineering" will be completed and ready for issue; and that the

"Examples of Applied Mechanics," already advertised, will be ready at the same time.

New editions of the College Manuals of "Roads" and "Bridges" are now available—and those of "Irrigation Works," "Surveying," "Examples of Estimating," and "Scantlings of Roofs," which are all out of print, will shortly be put in hand.

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It is possible that an Extra Number may be issued before I leave Roorkee, containing such original papers as I still have in hand. Of this due notice will be given.

# INDEX TO VOL. VII.

## LIST OF PLATES.

PHOTOGRAPHS.



ENGRAVINGS.



LITHOGRAPHS.

## No. CCLVI.

## THE NEW BARRACKS, ALLAHABAD.

The Specification and Estimate were framed in 1866 by Capt. D. Limond, who was Executive Engineer of the Division. The work has been carried on from time to time by different Officers, who succeeded each other in succession. The Contractors were Messrs. J. P. Fleming and J. Frizzoni.

The bricks, stone, tiling and timber were supplied by Government. The bricks and tiles were constructed under Mr. Beale, a professional brick and tile maker, sent out by the Secretary of State, and both are of very excellent quality. The stone was procured from the Purtabpore quarries, situated 30 miles up the Jumna. The slabbing for the floors was procured from the Sheorajpore quarry, on the Jubbulpore Line of Railway.

### Specification.

The foundation and plinth are of rubble masonry; superstructure of first class brick-work, pointed outside and plastered within.

Floors on the lower story are of 2-inch stone flagging, laid in mortar over a layer of consolidated brick ballast.

Floors of upper verandah are of two layers of 18-inch tiling, and one layer of 2-inch stone flagging, supported on wrought-iron beams and joists.

Floors of main ward, upper story, are of two layers of 2-inch flagging, supported on wooden beams, 24′ × 13″ × 7½″, placed 18 inches apart, from centre to centre.

Roof of main wards consists of timber trusses 7½ feet apart, (rafters 7½″ × 4½″,) carrying purlins 5″ × 2½″, placed 18 inches apart, from centre to centre, on which are placed cylindrical tiles 18 inches long and 3 inches diameter, set in mortar, and covered by Goodwyn tiles.

Verandah roofing consists of 2-inch stone flags under a 1-inch layer of bricks and 6 inches of concrete, supported on wooden beams, 9″ × 6″, placed $3\frac{3}{4}$ feet apart, from centre to centre. W. H.

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### Abstract of Estimate for 16 Half Company Barracks.

| | | Rs. |
|---:|---|---:|
| 302,636 | Excavation of foundation, at Re. 0-8-0 per 100 c. ft., | 1,513 |
| 45,648 | Concrete, at Rs. 16 per 100 c. ft., | 7,304 |
| 112,416 | Consolidation of brick rubbish round barracks, at Rs. 3-8 per 100 c. ft, | 3,935 |
| 173,000 | Rubble masonry in foundation, at Rs. 28 per 100 c. ft., | 48,440 |
| 159,216 | " plinth, at Rs. 28-8 per 100 c. ft., | 45,376 |
| 5,487 | Brickwork in foundation, at Rs. 28 c. ft., | 1,536 |
| 15,930 | " plinth, at Rs. 28-8, | 4,540 |
| 1,728 | Dressed rubble stone, at Rs. 1 per c. ft., | 1,728 |
| 395,666 | Brickwork in superstructure, lower stories, at Rs. 29 per 100 c. ft., | 1,14,743 |
| 30,368 | Do., 2nd class bricks being used, at Rs. 22 per 100 c ft., | 6,681 |
| 268,232 | Brickwork in superstructure, upper stories, at Rs. 30-8, | 81,811 |
| 58,666 | Arched brickwork, lower stories, at Rs. 32, | 18,773 |
| 42,224 | " upper stories, at Rs. 34, | 14,356 |
| 288,051 | Painting, at Rs. 4, per 100 s. feet, | 11,522 |
| 1,048,079 | Plastering, at Rs. 4-8 per 100, | 47,163 |
| 1,048,079 | Whitewashing, at Re. 0-6, per 100 c. ft., | 3,930 |
| 39,918 | Timber in beams, at Rs. 3 per c. ft, | 1,19,754 |
| 18,483 | Framed timber, at Rs. 3-8, | 64,690 |
| 64,690 | Teak doors and window sashes, at Rs. 1-2 per s. ft., | 72,776 |
| 29,056 | Ashlar, at Rs. 1-8 per c. ft., | 43,584 |
| 1,01,504 | Roof covering of main wards, consisting of Goodwyn tiles in mortar, laid in cylindrical tiles, at Rs. 20, | 20,301 |
| 98,552 | Roof covering of verandahs, consisting of stone flags 2 inches thick, overlaid with brick 1 inch thick and concrete, at Rs. 30 per 100 s ft., | 29,566 |
| 14,208 | Roof covering of Sergeants' Quarters, consisting of stone flags 2 inches thick, overlaid with cylindrical tiles and concrete, at Rs. 31 per 100 s. ft., | 4,404 |
| 56,736 | Ceiling, of huldoo or mangoe planking, laid on joists, at Rs. 16 per 100, | 9,078 |
| 335 | Tons of plate iron girders, at Rs. 240 per ton, | 80,400 |
| 1,714 | Mds. wrought-iron work in railings, at Rs. 20 per maund, | 34,280 |
| 1,808 | Mds. cast-iron work in piping, at Rs. 14 per maund, | 25,312 |
| 19,258 | Stone flagging to steps, at Rs. 25 per 100 s. ft., | 4,814 |
| 175,368 | Flooring of ower stories, consisting of 2-inch stone flags, laid in mortar over a layer of consolidated brick ballast, at Rs. 25 per 100 s. ft., | 43,842 |
| 73,760 | Flooring of upper wards, consisting of 2 layers of 2-inch stone flagging laid on beams, at Rs. 38 per 100 s. ft., | 28,029 |
| 90,832 | Flooring of upper verandahs, consisting of 2-inch stone flagging, laid in mortar over two layers of tiles (flat), at Rs. 30 per 100 s. ft., | 27,250 |
| 12,792 | Pitched facing, at Rs. 13 per 100 s. ft., | 1,663 |
| 463,088 | Earthwork in filling plinth, at Re. 0-12-0 per 100 c. ft., | 3,473 |
| 48,176 | Painting iron-work, at Rs. 3 per 100 (3 coats) s. ft., | 1,445 |
| 312,656 | Painting wood work, at Rs. 3 per 100 (3 coats) s. ft, | 9,380 |
| 16,448 | Stone louvre work, at Re. 1 per s. ft., | 16,448 |
| 736 | Sets of arm racks, at Rs. 2 each, | 1,472 |
| 736 | Sets of shelves and pegs, at Rs. 4, | 2,944 |
| 7,200 | Punkahs, at Re. 1 per r. ft., | 7,200 |
| | Total, | 10,65,156 |
| | Add contingencies, at 5 per cent., | 53,272 |
| | Grand total, rupees, | 11,18,728 |

# No. CCLVII.

## THE STREEVIGUNTUM ANICUT.

*Report by* Captain H. L. Prendergast, R.E., *Executive Engineer.*

The Tambrapoorney, which rises in the Western Ghats bordering Travancore and the Tinnevelly District, and, flowing eastward, falls into the sea a few miles south of Tuticorin, drains a large tract of hilly and wooded country which is under the influence of both monsoons, and therefore possesses not only an abundant but a never failing supply of water. This makes the Tambrapoorney for its size one of the most valuable sources of irrigation in this Presidency, and its waters are consequently very extensively utilized by a series of seven Anicuts, which, thrown across the stream in ancient times, fertilize, from side channels, a considerable breadth of land on either bank.

The last of these anicuts is at Murdoor, about twelve miles above the site at Streeviguntum that has been selected for the proposed new work, which has for its object the interception of the large quantity of water that finds its way by percolation, even in the driest weather, either through or under the various anicuts, or is returned to the stream as surplus from the channels on either bank, and which, together with the large volume of water brought down by the freshes, now escapes to waste.

The sketch plan of the country to the east of Streeviguntum shows the direction of the channels, and the land to be irrigated by them. The site of the anicut has been determined with reference to the existing system of irrigation on the north bank, which is also found to be the most suitable point for extending the irrigation on the south bank. The anicut is to be

built immediately below the present temporary dam, which supplies the Keelpadagay channel on the left bank of the river; the course of this channel is followed for about $2\frac{1}{2}$ miles, and a new channel is then traced to the south of the present cultivation, so as to avoid interfering with existing rights, past the village of Mungalacurchi, to join the Armugamungalum supply channel, where the surplus channel of the Perungoolum tank falls in. From this point there is at present a branch channel for the supply of the Coorkay tank, as also another old channel to Armugamungalum tank; and the main channel being carried northwards, above the Armugamungalum tank, to maintain the head of water, passes through the Paycolum tank, and following the line of bund of several small ruined tanks, terminates at the Korumpullum tank. The surplus of this tank will be conveyed to Tuticorin, and a sluice is provided to furnish a constant supply of water for the benefit of that town. It had been expected that irrigation might have been carried for some miles further to the north; but levels having been taken as far as 4 miles to the north of Tuticorin, it is found that beyond Korumpullum the land is altogether too high to admit of its being brought under the influence of an anicut at Streeviguntum.

On the right bank of the river, a new opening is made for the main channel, which at 300 yards distance meets and absorbs the Keelavycal, a channel that carries off the drainage from the cultivation under the large Tenkarrai tank, and flows into the Cadamba tank at $5\frac{1}{2}$ miles distance from the anicut head sluice. At the western extremity of the Cadamba tank, the main channel throws off a branch to the north, for the supply of the Ahtoor tank, as compensation for the loss of water in the Ahtoor river channel that will be caused by the anicut arresting the greater part of the river supply in the dry season: the Cadamba tank will receive its share of water at once from a sluice in the main channel, which turns to the south from the same point, and passes round the spread of the Cadamba tank, instead of flowing through it. By this arrangement the Government will retain the entire command of the water supplied by the anicut, to be apportioned both to the Cadamba tank and to the lands irrigated independently further on; the existing rights of the villages of Tenterapery, &c., will thus be maintained, while there will be no cause for the exhibition of that jealousy which the ryots are disposed to feel when their tanks are made to serve the purpose of benefiting their neighbours as well as

themselves. At the southern extremity of the Cadamba tank bund there is a small channel which carries off water from a high level to the Ammenpuram tank, 3 miles below; this channel is to be enlarged, and the anicut water on leaving the Cadamba tank will pass down the enlarged channel to the Ammenpuram tank and the contiguous Kanum tank; from the southern end of the latter, a new channel has to be excavated for a length of 5 miles, to the Ellapanaiken tank, throwing off a branch eastwards for the supply of the Trichendoor tank, and another small branch to Shonancatvele tank.

The Tambrapoorney differs materially from the Pennair and Palar rivers, which are swollen by short and uncertain freshes; for while floods of magnitude occur usually several times in the year, there is a constant moderate stream which, even so low down as Streeviguntum, never fails. The principal source of the Tambrapoorney is from the extensive valley above Papanassum, and this being within the influence of the south-west monsoon, a flood comes down as an ordinary occurrence in the early part of June. In the present season the river rose in the first week of June, and on the 7th there was a depth of 10 feet at Streeviguntum. For the next six months, or till the close of the north-east monsoon, the river is subject to floods of frequent recurrence: while the natural drainage from the hills keeps up a hot weather stream, that was calculated by experiment, opposite Streeviguntum in the present year, at 12 cubic yards per second; while also from the record of five years, it is found that during the month of March the discharge of the river is never less than 7⅓ cubic yards per second. But for six months of the year the volume of water in the river is not less than 79,200 cubic yards per hour, which, with the sectional area allowed, gives a discharge on each channel of 11 cubic yards a second, for a depth of 3 feet, or sufficient water for the irrigation of 39,600 acres of land at 2 cubic yards per acre per hour. The total quantity of water available for irrigation is thus arrived at:—

For six months, or for the full period of 125 days for raising the first crop, the discharge of the river at 22 cubic yards a second is 237,600,000 cubic yards, and allowing 48 cubic yards a day for each acre, or 6,000 yards for 125 days, there is water sufficient for 39,600 acres.

Next, considering fifty-seven days to elapse before the full quantity of water is needed for the second crop, the river discharges 15 cubic yards per second for a period of forty-five days, or a total of 58,320,000; and

1,350 cubic yards being required per day, at 30 cubic yards per acre per day for the second crop, 43,200 acres might be irrigated in this period. Again, for another term of forty-five days, taking the minimum river discharge at 7½ cubic yards per second, there is a total volume of 28,382,400 cubic yards, which would irrigate 21,024 acres at the same rate of 1,350 cubic yards per acre.

Now, the land to be brought newly under cultivation from the anciut is 21,254 acres, 15,000 acres being on the north side and 6,254 acres on the south side of the river. Add 4,091 acres of land at present cultivated on the north bank and 7,322 acres on the south bank, and there is a total of 32,667 acres; of which 19,091 acres are on the north, and 13,576 on the south, bank. For the first crop

| | Cubic yards. |
|---|---|
| The volume of water available is ... ... | 237,600,000 |
| And the water required for 32,667 acres is ... | 196,002,000 |
| Excess, ... ... | 41,598,000 |

For the first period of forty-five days for the second crop—

| | |
|---|---|
| The water available is ... ... ... ... | 58,320,000 |
| The water required is ... ... ... ... | 44,100,450 |
| Excess, ... ... | 14,219,550 |

For the second period of forty-five days for the second crop:—

| | |
|---|---|
| The water available is ... ... ... ... | 28,320,000 |
| The water required is ... ... ... ... | 44,100,450 |
| Deficiency, ... ... | 15,718,050 |

Or, throughout the dry season of the year, the quantity of water wanting is only 1,498,500 cubic yards. For the first crop there is an excess of water to the extent of 41½ million cubic yards over the volume required for watering 32,667 acres, viz., 196 millions, or an excess of about 20 per cent.; but in this calculation no account is taken of the floods by which an immense body of water is poured into the sea. The observation of an ordinary high fresh passing Palamcottah to a depth of 12 feet in the north-east monsoon gave the discharge past Streeviguntum (allowance being made for further drainage, and the Murdoor anicut intervening) at upwards of 2,000 cubic yards per second. The storage capacity of the tanks on the line of channel on the north bank is 15 million cubic yards, and on the southern line 20 million cubic yards of water; hence 35 million cubic yards may be held in reserve in case of a failure of the ordinary river supply, which at a safe computation gives about one-fifth more water than is required.

During the first half of the period in which the second crop is growing, there is an excess of water of nearly $14\frac{1}{4}$ million cubic yards, and in the latter half of the growing season there is a deficiency of nearly $15\frac{3}{4}$ millions. But before the second crop requires water, the freshes of the north-east monsoon will have come down, and the tanks will be filled, so that there is a store of 35 million cubic yards available, in addition to the gradually accumulating excess of $14\frac{1}{4}$ millions, to make good the want of $15\frac{3}{4}$ millions towards the close of the season.

To illustrate the capacity of the channels in carrying off the water in freshes: if we suppose only a depth of $4\frac{1}{2}$ feet of water in each main channel which will be given by a very moderate flood, the discharge down each channel is 21 cubic yards per second; or the supply obtained by both channels together is upwards of $3\frac{1}{2}$ million cubic yards in a day. Again, at the time of cutting the first crop, when no water is required to be admitted to the fields, and with only a slight use in the river for nine days, sufficient water will be poured into the tanks to provide for the deficiency of $15\frac{3}{4}$ million cubic yards for the second crop.

The Tambrapoorney being a perennial stream, and the discharge of water varying very much according to the time of year, as regulated by the West Coast monsoon, no provision is attempted for storing the flood waters, as the existing tanks will hold a moderate reserve, sufficient to provide against the very probable event of a failure of the ordinary flow after the north-east monsoon has ceased. While then every high fresh sends a large body of water to waste into the sea, it is altogether beyond the present scheme to utilise this excess of water. In the flat sandy plains near the coast, there are no natural facilities for storing a large body of water, and in fact there is no inducement to consider such a proposition, for there is but a limited area of land between the existing cultivation and the sea shore. If the flood waters of the river are ever to be turned to useful account, it must be in their being stored up in reservoirs before the river leaves the hills, or in moderate-sized tanks higher up, at any rate, than Streeviguntum. What the present project aims at is to secure the cultivation of the tract of land that has hitherto been the last to receive water, by admitting the first freshes at the beginning of the cultivating season,—to draw off the fields all the water (*i.e.*, taken at a minimum) that has hitherto run to waste during the dry season, thus ensuring the growth of a second crop on land that has had but a precarious supply for

one crop,—and to bring the remaining culturable land that is suitably situated under irrigation from the river.

In the calculations of water-supply, the unfailing stream of water from the hills is depended on for the culturable area. For as much as forty-five days of the cultivating season, the average daily supply is taken at the minimum, and after March, or in the most dry time of year, hardly any water at all is required for the fields; but there is also a stand-by in the event of a season of extraordinary drought, in the water drawn off the river on both banks, from the Murdoor anicut, 12 miles above Streeviguntum. On the north bank, the Peerungoolum tank, which is the last of the chain of tanks fed by the Murdoor channel, is so well supplied that it is never empty, and after a succession of floods the surplus water passes down to the Armugamungalum tank. This extra supply will now be caught by the new channel, and be available for distribution independent of the water in the river at Streeviguntum, while it may further provide a store against the diminution of water that commences in January, inasmuch as the floods of greatest magnitude come down during the north-east monsoon, which terminates in the month of December. The Paycolum tank, next beyond the Armugamungalum, may also obtain a large supply; this tank has hitherto been very badly off for water, and there has been very little cultivation from it; it will, however, be increased as to capacity, by the strengthening of the bund, and, in fact, become a considerable reservoir. On the south bank, there is a similar additional supply of water. The Tenkarri tank is filled by the channel from the Murdoor anicut, on the right bank, and the waste water from its calingula passes down to the Cadamba tank, so as to be in future a supplemental supply for filling directly the Cadamba tank, and also for the benefit of the lands further on.

From the Collector's statement of land that can be brought under cultivation, and the additional revenue to be thereby raised, the following details are obtained:—

*On the North Bank.*

| | | RS. | |
|---|---|---|---|
| 2,709 Acres, now one crop land, for second crop, at 2 Rs., | ... | 5,418 | |
| 10,000 Acres, dry cultivation, at 7 Rs. for two crops, Rs., | 70,000 | | |
| Deduct present assessment, „ | 4,000 | | |
| Increase, ... ... | ... | 66,000 | |
| 5,000 Acres waste, at 7 Rs. for two crops, ... ... | ... | 35,000 | 1,06,418 |

| | | | | |
|---|---|---|---|---|
| Brought forward, | ... | | | 1,06,418 |

*On the South Bank.*

| | | | | |
|---|---|---|---|---|
| 1,036 Acres, now one crop land, for two crops, at 2 Rs.,... | | ... | 2,072 | |
| 1,631 Acres, dry cultivation, at 6 Rs. for two crops, there being 1 Rupee already paid as dry assessment, ... | | ... | 9,786 | |
| 3,587 Acres, principally waste, at 7 Rs. for two crops, Rs. | | 25,109 | | |
| But deducting for present assessment, ... „ | | 1,000 | 24,109 | 35,967 |
| Total, | | | ... | 1,42,385 |
| Add the gain from the abolition of ordinary remissions, averaging, ... ... ... ... ... ... ... | | | ... | 10,000 |
| Grand Total, Rs., | | | ... | 1,52,385 |

Allowing 10 per cent. of the gross profits for repair and management, or Rs. 15,235, there remains a net profit of Rs. 1,37,150 per annum, or 16·48 per cent. on the capital to be expended in carrying out the works.

The Collector, in his statement of expected profits, sets down the assessment at his proposed reduced rate of Rs. 7 per acre for a double crop; but he deducts the present revenue of 4,091 acres on the north, Rs. 37,491, from the aggregate future revenue of the total acreage, to show the net gain. Now, it is manifestly unfair to deduct the present average rate* per acre, of Rs. 9, from the total revenue, the greater part of which is obtained from the lower rate. To institute a proper comparison, either the future assessment of the 4,091 acres should be deducted at the 7 Rs. rate, or the whole assessment should be reckoned on the higher rate. Hence the actual profits are shown above, on the Collector's low assessment, without regard to the higher rate already paid for a small portion

* Rate for dry land, 1 Rupee.
„ first crop, 4 „
„ second crop, 2 „

7 Rupees, total.

This rate is the average of Rupees 37,491 for 4,091 acres, but does not at all represent the real rate paid for a double crop; for there are 2,709 acres, for which the rate for a first crop is paid; and 1,382 acres for which the rate for a second crop is paid,

| | | | |
|---|---|---|---|
| Hence a rate of 1 Rupee for dry land will give Rupees, | ... ... ... | | 4,091 |
| For first crop, 7 Rupees, | ... ... ... ... ... ... | | 28,637 |
| For second crop, 3½ „ | ... ... ... ... ... ... | | 4,837 |
| Total, 11½ „ | ... ... ... ... | Rupees, | 37,565 |

Thus the average rate of assessment is about Rupees 11½, without making any allowance for remissions, which are, for this land, usual and not exceptional.

of the land. Again, if a moderate water-rate of Rs. 4 per acre were to be levied, as distinct from the ordinary wet assessment, the additional return on 23,963 acres would be Rs. 95,852, and the gross profits 28 per cent.

The *Anicut* is to be 1,380 feet in length between the wing-walls, to be raised 6 feet above the average level of the deep bed of the river, and the width at the crown to be 7½ feet; there is a front slope of ½ to 1, and in rear a perpendicular fall on to a cut-stone apron 24 feet wide, and 4½ feet in depth: beyond, there is a rough-stone apron of the same depth. and 36 feet in width, protected by a retaining wall. The foundation of the body of the work and of the cut-stone apron in rear are to be of brick-in-chunam, laid on wells sunk 10½ feet in the sand, and raised 4½ feet above the wells, including the cut-stone covering; the retaining wall to be built of stone-in-chunam will also rest on a line of wells, to be sunk to the same depth, 10½ feet. The body of the anicut is to be of brick-in-chunam, faced throughout with cut-stone, and furnished with a set of undersluices at each extremity of the work to let off sand and surplus water. Each set of sluices is to consist of nine vents of 4 feet width each, lined with cut-stone; it was originally intended to have three more similar sets of sluices at equal distances throughout the length of the work, but, with the example of the Kistna anicut, it is now considered preferable to dispense with the intermediate sets of sluices.

The original estimate also provided for a bridge of thirty-three arches of 36 feet span, and 9 feet rise, with piers 15 feet in height above the apron, to carry a roadway 15 feet in width between the parapets; but as the anicut is not situated on any line of road, it is now felt that the expensive construction of a bridge is not a legitimate charge to a work of irrigation, but should be carried out, hereafter, under the head of "Communications." Still with a view to economy and a saving of time in future, it is proposed to build the foundations of the thirty-two piers, each 6 feet thick, to the same depth as those of the body of the anicut, supported by wells, as also the foundations of the wing-walls, in order that the superstructure of a bridge as described above may at any time be built.

It is found by calculation that a height of 6 feet for the anicut allows of a convenient slope of 1½ feet per mile down each of the main channels

for the first few miles, the floor of the head sluice being 6 feet below the crown of the anicut. Owing to the loose sandy nature of the soil, (in many places sand,) the main channels must have side slopes of 2 to 1 : the channels are not designed to carry off water rapidly, as in arresting freshes of sudden rise and brief duration, but width is required to enable the requisite body of water to pass down with moderate velocity.

The top of the wing-walls of the anicut are brought to a height of 3 feet above the level of a maximum rise of the river, the afflux caused by the anicut during a flood of magnitude is hardly appreciable (being calculated at less than 3 inches) from the increased velocity, and no precautionary measures are required to prevent the river topping its banks, as there is an artificial bund along each bank, for some miles, both above and below the site of the anicut.

The northern channel for the first 7 miles, and the southern for $5\frac{1}{2}$ miles, have both a fall of $1\frac{1}{2}$ feet per mile, with a bottom breadth of 36 feet ; the sectional area of each will be $6\frac{1}{2}$ square yards, and the hydraulic mean depth about 16 inches, when there is a depth of water of 18 inches in the channel. Hence, by Neville's Hydraulic rules, the velocity is about 20 inches per second ; and the discharge becomes $3\frac{2}{5}$ cubic yards per second, as the minimum supply of water in the channel during the cultivating season. With 3 feet of water in a channel, the discharge will be 11 cubic yards a second, as the normal state of the channel for at least six months ; and when $4\frac{1}{2}$ feet depth of water is admitted, at the time of freshes, the delivery of the channel will be about 21 cubic yards per second. On these data, the supply of water at different seasons, and the area of land thereby irrigable, have been calculated.

In reckoning on the supply of water derivable from the river, the additional supply by the rain-fall has been neglected, for the rain-fall is but insignificant ; the average rain-fall in a succession of years being 21·06 inches, and that in a very bad season only 11·68 inches ; a constant stream of water is also depended on for the cultivation, not storage in tanks to be maintained by the drainage of the country, in the short season of the rains.

But to provide for the disposal of the natural drainage, and also of the surplus water passing from the cultivation above the lines of new channel, a further valid reason exists for these channels having a considerable capacity in width, and for their sectional area being greater than would be

necessary only for the passage of water actually requisite for irrigation. In addition to other escapes for storm-water, there is on the northern line a dam 200 yards in length, with under-sluices, across the Oopaur, Oday, or jungle stream; and on the south side there is an extensive calingula in the Cadamba tank bund, measuring 330 yards in length.

The wing-walls of the anicut are carried round by a curve to join the lower wing-wall of the head-sluice on each bank; on the right bank the head-sluice contains three vents of 4 feet, on the left bank the head-sluice has four similar vents, inasmuch as the area of land to be irrigated on the north bank is greater than that on the south.

*North Channel.*—On the north bank, at a distance of $2\frac{1}{2}$ miles from the head-sluice, there is to be a division sluice for the irrigation of the Keelpadagay lands, where the new channel leaves the old one at D. on the sketch plan. This sluice consists of two vents of 2 feet width by 4 feet, and is capable of discharging 24·6 cubic feet per second, with a depth of 18 inches of water in the channel.

Five miles on, a head-sluice is provided for the present branch channel to the Coorkay tank, the sluice has two vents of 2 feet width each and 4 feet height; hence it is calculated to discharge 14,514 cubic yards an hour, for storage in the tank, when the channel is running 4 feet deep. Close beyond the above, there is a division sluice, serving also as a surplus calingula for the supply of the Armugamungalum tank. The sluice contains three vents of 4 feet width each and 6 feet height, which will discharge 28,281 cubic yards per hour, with the ordinary flow of 3 feet in the main channel, and in flood times will send down 79,993 cubic yards per hour for storage in the tank. The waterway of the calingula is 10 yards in length, and supposing the water to pass over 2 feet deep when the Perungcolum surplus channel is running, the discharge over the calingula will be 38,486 cubic yards per hour. Over this calingula there is a bridge of 30 feet span, and a causeway leads to another bridge of the same dimensions over the main channel; this arrangement being necessary to maintain communication along the road from Yeral through Siruthundoo to other villages to the north.

Following the main channel, at a distance of about $2\frac{1}{2}$ miles, a jungle stream falls into the Armugamungalum tank; and to allow this to discharge into the tank, when in flood, there is a calingula of 150 feet in

length and 4½ feet high. In the body of the calingula there are ten vents, each of 4 feet; and if the stream is in flood, a depth of 2 feet over the calingula will carry off 192,434 cubic yards per hour, which is ample provision for the drainage of the lands above. After another half a mile, in consequence of the rapid rise of the ground to the west, the main channel falls into the Paycolum tank, the bund of which is to be strengthened and slightly raised where necessary.

From the floor of the calingula of this tank there is a fall of 1 foot per mile along the line of bund of several small ruined tanks to the Korumpullum tank: these bunds will be strengthened to a proper section, and calingulas are provided with sluice vents to pass on the ordinary flow from the main channels, which will also be closed in order to obtain storage and pass the surplus water on over the crown.

Within a mile from the Korumpullum tank to the south, the Oopaur jungle stream crosses the line of water-supply; this stream runs in several widely diverging channels, and, when swollen by heavy rain, spreads over a broad strip of land; for the disposal of floods, a long dam or calingula, 600 feet between wing-walls, is provided, and the banks on either side are further protected by a revetment wall for a length of 225 feet, to be built on deep foundations. In the body of the work, which is 4½ feet high, there are twenty vents of 4 feet each; in a heavy burst of monsoon, supposing the water from the stream to rise 3 feet above the crown, the discharge per hour will be 1,414,099 cubic yards. To compare this with the volume of water liable to be brought down, a maximum fall of rain is taken at 8 inches in the twenty-four hours. Along the coast of Southern India the rain cloud is known to take its course along a narrow belt of country, and in the north-east monsoon its direction is not far different from that of the coast line; hence its path intersects, nearly at right angles, the general course of the rivers which run down from the west. In the case of the Oopaur, it is assumed, that there may be

| | |
|---|---|
| A fall of 8 inches over about one-fourth of the drainage area, or, ... ... ... ... ... | 80 miles. |
| 4 inches over another fourth, or, ... ... ... | 80 „ |
| and 2 inches over the remainder, ... ... ... | 182 „ |
| Total, ... | 342 square miles, |

and allowing one-fourth of the rain-fall to run off, there is a discharge of

1,186,546 cubic yards an hour. Thus the dimensions of the dam are sufficient to carry off the drainage from an excessive fall of rain.

Beyond the Korumpullum tank, the channel is carried on through four vents of 4 feet width, with a fall of 1 foot a mile, to Tuticorin, while in the monsoon, the surplus water brought into the tank by drainage will pass over the crown of the calingula. The channel will cut off the drainage of the ground on the north, and prevent the accumulation of water in the low land to the south, which is thus reclaimed for irrigation. While then the duty to be ordinarily performed by this channel is merely that of supplying fresh water to Tuticorin, the channel is liable, at certain times, to have a considerable accession of flood-water, and the fall given, viz., 1 foot in a mile, is the greatest possible, as it terminates at the high tide level: hence on calculating the amount of drainage that the channel receives and intercepts, a bottom width of 24 feet must be allowed.

The present principal outlet for the discharge of waste water along the course of the main channel to the south of the Oopaur river is the calingula of the Armugamungalum tank; the capacity of this calingula exceeds that of the two new calingulas provided in the channel bank, and the work, therefore, does not require alteration.

The Oopaur stream, however, must not be left in its natural condition, for the several channels in which it is divided meet again in two lines of drainage, or rather these two lines indicate the general direction to the sea, for the water spreads promiscuously over the country and lodges in extensive swamps. To remedy this, the drainage to the north will be cut off, and the whole of it will be kept within bounds, to follow the line to the south and enter the sea at the natural outlet, near the main mouth of the river. The fall of the ground lies in this direction, as seen by the contour plan, and from the wing-walls of the dam across the Oopaur a bank will be thrown up on each side of the drainage channel to a height of 6½ feet. The deep bed of the channel is about 4 feet in depth and 300 feet wide, a berm of 100 feet width is given on each side, and by the dimensions thus fixed (the excavation for the bunds being all taken from the inside) the channel will carry off a volume of 1,294,705 cubic yards of water per hour. Thus the channel will dispose of the flood-waters passed on from the dam, calculated above at 1,186,556 cubic yards per hour.

The minor works, on the north side of the river, besides those specified

above, are a dam across a sandy stream falling into the main channel, within 300 yards from the head sluice.

A bridge of 36 feet span for communication with the villages north of the channel;

A syphon sluice to carry off the drainage from the fields of Perungcolum under the main channel;

A small supply sluice near Mungalacurchee near E. on the plan;

A bridge of 30 feet span on the road between Mungalacurchee and Perungcolum; a similar bridge on the Palyacoil salt road marked H.;

And four calingulas, each of 24 yards length, and furnished with four vents of 4 feet width at the extremities of the Paycolum, the Pottacolum, the Chinnaswamy Naick, and the Korumpullum tanks.

The estimated cost of the channels and subsidiary works on the north-side is Rs. 2,97,940.

*South Channel.*—On the south bank, at a distance of 5½ miles from the head sluice, the main channel arrives at the Cadamba tank. At the entrance to the Cadamba tank, where there is at present a dam that retains the water in the tank and prevents it flowing up the Keelavycal channel, dividing works are proposed for three-fold purpose, viz., for supplying direct the Cadamba tank; for a channel on the left bank to the Ahtoor tank; and for carrying on the main channel on the right bank, round the Cadamba tank.

For the Ahtoor channel, there is provided a head sluice of two vents, each 2 feet wide by 4 feet. For the Cadamba tank, the head sluice consists of four vents, each 4 feet wide by 6 feet high, over which there is a platform bridge to give communication along the left bank of the channel; close to this there is another head sluice of three vents, each 4 feet wide and 6 feet high, for the channel round the Cadamba tank.

The Ahtoor branch channel has a bottom width of 12 feet, side slopes 2 to 1 and a fall of 1 foot in a mile; with this section, the discharge at a depth of 3 feet is 3⅗ cubic yards a second (or double the volume needed for the 3,000 acres dependent on the channel supply). At a distance of about half a mile, the branch channel crosses the Tenterapery river channel, the latter being carried under by an inverted syphon; then passing under the Trichendoor road, at about 1½ miles further on, it crosses by an aqueduct the old Ahtoor river channel, and falls into the Shedavycal tank. The tract of land between the old Ahtoor channel and the river

will thus be brought under cultivation as far as Shedavycal, and the old tank being strengthened, the stream of water will be passed on by a calingula, of 30 feet length for the supply of the Ahtoor tank. In addition to the aqueduct and syphon sluice, there is provided a platform bridge of two vents of 4 feet each, on the Trichendoor road; another similar bridge on the road leading to Yeral across the river, and an ordinary sluice of irrigation in the Shedavycal tank bund.

The main channel on leaving the dividing works has a bottom width of 24 feet side slopes of two to one, and a fall of 1 foot per mile, for a length of 8 miles, at the end of which the channel falls into the Ammenpuram tank. When running 4 feet deep this channel will convey 12 cubic yards per second for the supply of the Ammenpuram tank; at a distance of nearly 2 miles from the head sluice, the channel is taken under the surplus stream from the Tenkarrai tank by an arched tunnel of four vents, each 4 feet wide and 5 feet high, with a water-way of 90 feet length, and, at the southern extremity of the Cadamba tank bund, joins in with the present high level channel leading down to the Ammenpuram tank. The section of this latter channel is increased both by deepening and widening, width being for these 3 miles especially requisite, as the channel skirts the edge of the hills of red sand which are loose, and much affected by the strong westerly winds.

The Ammenpuram tank is separated from the Kanum tank by a calingula, to be built 24 yards long and 5 feet high, and with four vents 4 feet wide; a similar calingula is provided at the southern extremity of the Kanum tank, to admit of the constant stream flowing through the tanks to the channel beyond. On leaving the Kanum calingula, the channel is continued with the same section as before, along the slope of the land that falls rapidly from the Red Hills, for a distance of 5 miles, to the Ellapanaiken old tank, which is its termination. This latter section of the channel is of greater width than would be necessary merely to convey the water for irrigation: but the channel cuts off the drainage of the land above entirely, the soil is sandy, and a greater fall than that allowed is not attainable; hence in providing for a maximum fall of rain, it is not safe to reduce the channel section. A branch channel is thrown off at 1½ miles above the Ellapanaiken tank, with a bottom width of 12 feet, and of the same capacity as the Ahtoor channel. This branch channel will supply the town of Trichendoor with fresh water in filling the old tank

which is to be restored for the irrigation also of the land below it. A regulating dam of 15 feet length and 4½ height is provided where the branch channel leaves the main channel: one sluice vent of 3 feet width will pass on the supply of water for irrigation, and flood-water will flow over the dam.

Another similar regulating dam is provided a short distance below the Kanum calingula for the branch channel, of about a mile to the Shonancatvele or Thulukencolum old tank. The bund of this tank is to be restored, two irrigating sluices are also provided, and a surplus calingula of 30 feet length.

The other works estimated for consist in the restoration of the old Ellapanaiken tank, with a surplus calingula of 30 feet length, for the discharge of the monsoon drainage into the swamp a mile below, which has its exit into the sea, some miles on, near Colasagarapatam. A surplus calingulah is also to be provided for the Trichendoor tank, and an irrigating sluice.

The other minor works are ten irrigating sluices along the channel between the Kanum and Ellapanaiken tanks, and six irrigating sluices in the Ahtoor branch channel.

The cost of the channels and subsidiary works on the south side is Rs. 3,02,682.

Within the high belt of land along the sea shore, between the salt pans and Trichendoor, there are low lying swamps, marked on the sketch map: and levels have been taken over these parts to ascertain if it is possible to drain them off. They are found, however, to be so very low that such a measure is not practicable, and the idea of bringing them under cultivation has consequently been abandoned.

A small tiled bungalow is provided for in the estimate, consisting of two rooms, for the occupation of the resident Executive Officer, and for the safe keeping of the Office records, instruments, &c., during the progress of the works. This will be built as near as convenient to the site of the anicut, there being at present no building at all in the vicinity. Provision is further made for erecting temporary sheds, at distances of ten miles a part, for the general accommodation of the Engineering staff, Contractors, and other persons connected with the works.

Under Superintendence, no entry is made in the estimate for the salary

of the Executive staff, as the general establishment will furnish the Officers and Overseers; but due provision is made for the Subordinates of lower grade that come under the head of Petty Establishment, and also for the Office establishment, which is set down on the scale of a first class Range Office.

The rates are taken in general as those prevailing in the Tenkara Talook; for some of the masonry works, a higher rate must be allowed than for the head works, as both bricks and stone, as well as chunam, must be conveyed several miles. No increase in prices has been made in anticipation of Railway operations being commenced from Tuticorin, but the sooner the anicut works are put in hand, the less will the Government suffer in consequence of the demand for labor on the railway, and the rise of prices that must then inevitably take place.

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### Memorandum.

The dimensions of the head sluices have been determined with relation to the height of the anicut. When the river water stands on a level with the crown of the anicut, the head sluice on the north bank will discharge about 21 cubic yards per second, or double the volume required for irrigating the land, viz., 19,091 acres; the flow of water in the river being constant, and there being partial storage, it is held that twice the actual quantity to be used will be sufficient, evaporation and other losses inclusive. If the crown of the anicut had been 1 foot lower, the head sluice must have been enlarged to allow of the same discharge of water; but from the tendency of a river to silt up above an anicut, necessitating an increased height being given to the work after a few years, it appears advisable to place the crown of the anicut on that level, which will allow a sluice of moderate dimensions to discharge the required quantity of water.

The width of the body of the anicut at top, 7½ feet, is somewhat great, but in the event of the work being raised in course of time, it will be an advantage having a good top width upon which to build.

The discharge of the river has been taken from the record of the average of five years, which gives 22 cubic yards a second for six months, and never less than 7⅓ cubic yards up to the end of the cultivating season. Now, considering that only the minimum discharge is reckoned on for as much

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The discharge of the river has been taken from the record of the average of five years, which gives 22 cubic yards a second for six months, and never less than 7⅓ cubic yards up to the end of the cultivating season. Now, considering that only the minimum discharge is reckoned on for as much

as forty-five days, it is taken as a fair average calculation that, for the other forty-five days, the discharge is 15 cubic yards a second.

If, however, only the minimum discharge were assumed as available for the whole ninety days of the second crop—

| | Cubic yards. |
|---|---|
| There would be water available .. .. .. | 56,764,800 |
| Do. required, .. .. .. | 88,200,900 |
| Deficit, .. .. .. | 31,436,100 |

and to meet this extreme case there is storage capacity to the extent of 35 million cubic yards, to be obtained by all the floods of the north-east monsoon.

The land commanded by the channels is limited on the north side of the river by the sand hills to the west of the line of channel, as far as the Oopaur stream, beyond which on the north the ground is all several feet above the channel level, and no extension of the channel can be made.

On the south bank, the channel likewise is taken round the edge of the hills of sand, and the cultivation is limited by the backwater running up from the sea. The minimum supply of water from the river not being quite enough for the irrigable area, recourse is had to storage for that deficiency of water by making use of the existing tanks. More water is available for several months, but is not wanted; more land might be irrigated, but is not available.

It does not appear likely at present that the channels will ever be required for navigation, and therefore there have been alterations made in the course of the channels, from those originally proposed, when it was considered that the East Coast canal might be extended to the south of the peninsula: the development of the railway system in the last few years having altogether changed the prospects that were entertained formerly of improved means of communication.

On the north bank, the channel might have been taken along the upper spread of the Paycolum tank, but the expense of 4 miles of excavation is saved by letting the channel into the tank; again, the channel might be continued above the tanks beyond the Paycolum, but the bunds of these tanks, which have fallen into disuse from want of water, provide a line of embankment that only needs restoration.

On the south bank, the channel might have been kept up at the edge of

the Ammenpuram and Kanum tanks, but the cost of two miles of channel is avoided by making use of these tanks.

The channel leading into Tuticorin must carry off the drainage from the north, and its section is determined from the drainage area in a heavy burst of monsoon; the channel also cannot pass the drainage across by escapes through the land to be brought under cultivation, without embankments along the course the water would have to take, and thus further intercepting the field channels from the Korumpullum sluices.

Likewise, on the south, the channel from Kanum tank must conduct the drainage by the Ellapanaicken tank, to the natural outlet into the sea further south.

ABSTRACT OF ESTIMATE.

| | RS. |
|---|---|
| Anicut, .. .. .. .. .. .. .. | 1,48,500 |
| Northern channel, .. .. .. .. .. .. | 1,28,370 |
| Subsidiary works of do., .. .. .. .. .. | 1,69,570 |
| Southern channel, .. .. .. .. .. .. | 1,93,850 |
| Subsidiary works of do., .. .. .. .. .. | 1,08,832 |
| Cost of land, superintendence, plant, &c., .. .. | 82,878 |
| Total, .. .. | 8,32,000 |

MADURA,
*August 8th*, 1868.

H. L. P.

NOTE BY CHIEF ENGINEER.

The present project offers a very good example of the change that has occurred in the prices of labor and materials since Colonel Horsley's time, 1855. Captain Prendergast in August, 1867, sent in a comparative statement showing what the works would cost, by merely altering the rates allowed by Colonel Horsley, and the estimate by the latter Officer was thus raised from Rupees 3,28,954 to 7,50,000, or more than double. The following are the former and present rates of some of the most important articles:—

| | 1855. | | | 1867. | | |
|---|---|---|---|---|---|---|
| Brick-work, per cubic yard, .. .. .. | 2 | 0 | 0 | 5 | 0 | 0 |
| Cut-stone, .. .. .. .. .. .. | 7 | 0 | 0 | 12 | 0 | 0 |
| Wells, .. .. .. .. .. .. | 2 | 4 | 0 | 5 | 8 | 0 |
| Jungle-wood, per foot, .. .. .. .. | 1 | 4 | 0 | 3 | 8 | 0 |
| Earthwork, .. .. .. .. .. | 0 | 0 | 8 | 0 | 2 | 0 |
| Kunkur, .. .. .. .. .. .. | 0 | 12 | 0 | 1 | 8 | 0 |

As regards the designs for the works, I am of opinion that they have been prepared with much care and judgment. In the case of the anicut

only has it appeared to me necessary to make any additions or alterations worthy of notice.

*Anicut.*—A row of wells has been added at the rear of the floor to secure it against risk of subsidence. The flanks in rear have been altered from straight lines to curves, as the violent eddy from the former would produce an erosive action on the bank of the river down-stream. Additional rough stone, 120′ × 24 × 3, has been allowed for an extension of the apron in rear of each set of under-sluices, and rough stone has also been added as a protection to the base of front curved wing-wall, against a set of the river. Seven counterforts have been added to the wing-walls and returns at each flank of the anicut. The mean thickness of walls should not be much under one-third height. The batter should also rather be to the outside than inside. These additions will raise the estimate from Rupees 1,48,500 to 1,59,500.

The arrangement of under-sluices is, in my opinion, judicious. The object of under-sluices is not to prevent a *general* silting up of the bed of the river above the anicut, but to keep channels clear in front of the head-sluices. So long as this object is accomplished, I do not see that any practical injury can result from the silting of the bed in the rest of the river channel, and I consider the practice in the South of India of allowing a series of small vents, which in the larger anicuts at the Godavery and Kistna are arched over, preferable to large openings, because the resistance offered by the intervering piers prevents an undue acceleration of velocity when the river rises several feet above the anicut.

It will be observed that the retaining and wing-walls are not to be built on wells, but Colonel Wilkieson reports that the same soil for foundations will be encountered as was met in the foundation at the south head-sluice (built during past dry season), that is, compact clay.

A section of the river is given on rather a small scale in the longitudinal section of the southern channel. The height of an ordinary fresh above the average deep bed of the river, or the proposed level of sluices, may be taken at ten feet.

| | Sq. Feet. |
|---|---|
| Total sectional area above level of sluices 1,400 × 10 = | 14,000 |
| Sectional area from same level to level of bed, ... ... | 4,679 |
| Present waterway, ... ... ... ... | 9,321 |
| Obstruction by anciut—area of section, ... ... ... | 7,848 |
| Proposed waterway, = 14,000 − 7,848 = | 6,152 |

or, with a ten feet fresh, one-third the waterway will be obstructed, or the velocity will be increased in the proportion of three to two. Average depth of water in natural condition of river is seven feet, velocity 5 to 5 6 feet per second, according as the fall is taken at two-and-a-half or three feet a mile, within which limits the actual fall of surface is likely to be, the distance to mouth of river being sixteen miles, and the total fall forty feet. The velocity of the water passing over the dam, supposing the surface to remain the same as before would, therefore, be only 8·4 to 7·5 feet per second, and the afflux corresponding to the natural mean velocity of 5·6 feet would be slightly under two feet. This is moderate. On the Kistna Anicut, which is reckoned at twenty feet above the ordinary river bed, when the river in its natural state is four feet above the crown, the afflux is from three and three-fourths to four feet, and the velocity twelve feet per second; and on the Godavery Anicut with a like depth on the crown the afflux is nearly three feet.

*Head Sluices.*—The south sluice, as before observed, was built by Lieut. Shepherd, in order to secure a supply to the Cadamba tank during the present season. It has three vents of four feet. When the water in the channel has a depth of three feet, the velocity is two-and-a-half feet per second, and the discharge, in round numbers, 300 cubic feet per second. This passed through a sluice, twelve feet by three, waterway, gives a velocity of 8·33 feet per second, and to generate such a velocity. the head must be such that $v = 5 \sqrt{h}$; hence $h = 2 \cdot 77$ feet. The required supply would therefore be delivered before the water rose to the crest of the anicut. It is desirable that the waterway of the sluices should be kept within moderate limits to reduce the risk of accidents in sudden floods; still the northern head-sluice, which moreover has to supply a larger area than the south, has been judiciously allowed an increased waterway of four vents, or sixteen feet in all. This will reduce the velocity and afflux corresponding to a discharge of 300 cubic feet per second to six-and-a-quarter feet per second and 1·56 feet, respectively.

J. C. A.

# No. CCLVIII.

## FOURACRES' WELL EXCAVATOR.

*Report on a new Tool, invented by* Mr. C. Fouracres, C.E., *for Sinking Well Foundations.* By G. R. Long, Esq., *Exec. Engineer, Dehree Division.*

The accompanying drawing will make the construction and action of the Excavator clear with very few words of explanation; it consists of—

*1st.*—A spear of 1 inch square iron, 12 feet long, with shackle at the top to sling it by, and a cross-head at bottom.

*2nd.*—Two segmental scoops, hinged on the ends of the cross-head, and forming when closed (the edge of one slipping just within the other) a bucket of rather more than the third of a cylinder. Materials, sheet-iron and angle-iron for corners.

*3rd.*—Two iron collars sliding loosely on the spear, and connected, at a fixed distance, asunder, by a second side spear. To the lower collar are attached two hinged rods to open and shut the scoops. To the upper collar, a small wooden platform is fixed, on which two men can stand whose weight will force down the instrument, or, in working below water, an iron weight can be substituted.

*4th.*—A lever hinged on the top of the spear to open the jaws of the scoop when over the discharge platform.

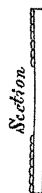
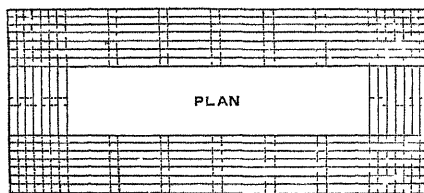
*5th.*—There are also two stops on the spear, and a spring clasp to keep the jaws open while the scoop is being lowered.

The action is very simple. The machine is slung over the well or block

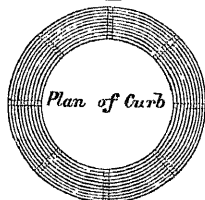
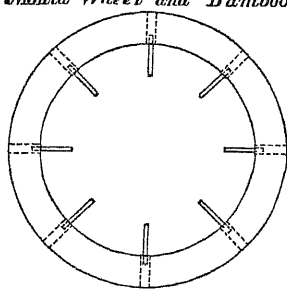
by tackle and pulleys worked by a windlass, from any convenient form of staging; it is lowered, with the jaws in the open position, till it rests on the bottom; the two attendants step on the platform, and one with his foot releases the spring clasp; the windlass men at once wind up, but the weight of the men keeps the scoop from rising till the jaws have closed and it is full of sand; then all rise together; the two men step off on the sides of the well, and, as the full bucket rises to the level, they sway it over a wooden platform at the side, and pull smartly at the lever; the jaws open, and the catch holds them; so the sand falls out on the platform; the machine swings back, and is immediately lowered again, while the sand is shovelled or run away. This can be repeated at the rate of one lift per minute, lifting $1\frac{1}{4}$ to $1\frac{1}{2}$ cubic feet each time.

Before proceeding to describe the actual experiments, I will state, as you desired, the nature of the well sunk, and of the curbs used, as the latter are believed to be new, have been found sufficient for the purpose, and are very economical.

The wells were not round wells, but rectangular blocks: one was $10\frac{1}{2}$ feet by 6 feet externally, with 18 inches walls; the other, $10\frac{1}{2}$ feet by 5 feet, with 15 inches walls, built of random rubble stone, in mortar of soorkhee and kunkur lime, not plastered, but rough outside; they had been built about a fortnight before they were sunk.

The curbs were simple platforms of small solid hill bamboos, laid close side by side, well lashed at the corners, and with under cleats of short lengths lashed on for strengthening. All crevices were stuffed with grass, and care taken that no bamboos projected beyond the masonry.

The first course should be through stones, though that was neglected on this occasion.

When round wells are to be sunk, the bamboo curb is thus made:—A mould wheel of timber about 9 inches by 4 inches is prepared, whose

inside diameter is the outside diameter of the curb; holes are pierced

through this to receive short pieces of solid hill bamboos, projecting inward by the breadth of the curb; these are wedged in; similar bamboos, split in two, are now coiled round and round (the mould wheel being supported 2 feet above the ground) and lashed to the bamboos till the required breadth is attained, when the whole is sawn out. If greater stiffness is needed, bamboos can be coiled both above and below the cleats; in fact a wedge-shaped curb could be made. But the single bambo has been found sufficient to sink wells 6 feet in sand without cracking.

The cost of these curbs is about as follows:—

| | RS. | A. | P. |
|---|---|---|---|
| 1. Oblong block, $10\frac{1}{2}$ by 6 feet, 18 inches walls— | | | |
| 40 bamboos, small, ... ... ... ... ... | 0 | 5 | 0 |
| String, ... ... ... ... ... ... ... | 0 | 2 | 0 |
| Labor, ... ... ... ... ... ... ... | 0 | 2 | 0 |
| | 0 | 9 | 0 |
| 2. Circular wells, 5 feet inside, $6\frac{1}{2}$ out— | | | |
| 20 bamboos, ... ... ... ... ... ... | 0 | 2 | 6 |
| String, ... ... ... ... ... ... | 0 | 2 | 0 |
| Labor, ... ... ... ... ... ... ... | 0 | 2 | 0 |
| | 0 | 6 | 6 |

I have now to describe the actual trial of the instrument, the difficulties found on the first occasion, and how they were overcome on the second.

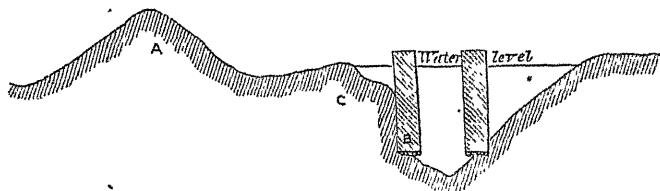
The first block sunk on June 16th was $10\frac{1}{2}$ feet by 6 feet, 18 inches walls, height 6 feet. The instrument worked satisfactorily, bringing up good loads, but rather slowly, one load in a minute and a half being the quickest time; the men were quite new to the work, and the disengaging

spring had not at this time been added. In the first $3\frac{3}{4}$ hours the block sunk 2 feet, showing 130 feet actual excavation, besides what might have blown in below.

On this occasion, no platform was provided to receive the sand, which was merely discharged from the jaws of the Excavator over the side of the well. The effect of the heavy weight of sand continually thudding down some feet on the sand beneath, which was barely above water level in the river, was to make a quicksand of it; and it became evident that the sand was blowing in below. In the second 3 hours the progress was only one foot.

A man was than set to shovel away the sand as it fell. But this did not suffice: the next foot took $5\frac{1}{2}$ hours to sink, and a crater formed round the well. In three hours more, the sinking was only 4 inches; and, large stones coming up, a diver was sent down, who reported that the flat side of the well, not having the same strength as a round well, was broken in.

All this time the tool itself was working as well as at first.

The cross-section of the well, &c., at this time was thus: scale 12 feet to an inch :—

It was very clear that the weight of sand at A., and the continual falling of the sand on C., had caused the breach at B.

The tool worked as well, and brought up as full loads out of $6\frac{1}{2}$ feet of water, as it had done at first.

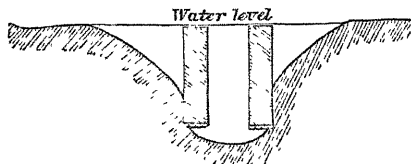
Two beds of pebbles were passed through; the only trouble these caused was, that when one jammed in the jaws of the Excavator, part of that load of sand was washed out and lost.

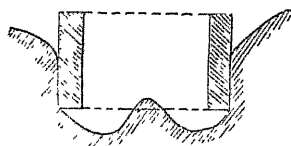
The second experiment on 25th June was with a block $10\frac{1}{2}$ by 5 feet, 6 feet high, with 15 inches walls. The working gear had been improved,

a scaffold to receive the sand added, and the spring disengaging catch added to the Excavator, which saved much time in the working.

The loads came up regularly at one per minute on the average, and the sand was deposited on the platform as fast as two men could shovel it away to 15 feet distance.

In an hour the block had sunk 9 inches; in $2\frac{3}{4}$ hours, 2 feet 6 inches nearly; in 6 hours, 4 feet 11 inches, and in 9 hours, 6 feet 3 inches, and the top 3 inches below water level, when work was stopped. Two beds of pebbles, as before, were passed through. No diver at all was employed.

Only a small crater was formed round the well, and the cross-section when completed was as in margin—scale as before.

The only precaution taken to ensure even sinking was to work the machine chiefly at the two ends, so that the longitudinal section at any time might be as under.

The block being thus supported at the two ends and in the middle, sank steadily without the least crack; occasionally a bite was taken from the middle in passing the machine over.

By the best calculation I could make of the sand taken out both by the displacement of the well and from the crater (part of which was previously formed by the river current), the sand dredged out was 550 cubic feet; taking average number of lifts at 50 per hour for 9 hours, gives 1·22 cubic feet as the average content of a bucket, including the half-empty ones.

Averaging the wages of the nine men employed at 2 annas 6 pies, and the time at a day and a half, gives Rs. 2-1-9 as cost of excavation in sinking a well 6 feet deep, or Rs. 3-13 per 1,000 feet only.

The men employed were, four at the windlass, two to guide and work the tool, one to shift tackle, two to shovel sand.

To give a general estimate of the cost of a block sunk by this means I think would be rather difficult till we have more experience, but the following may be taken as an approximation.

*Block* $10\frac{1}{2}$ *feet by* 5 *feet, walls* 1 *foot* 3 *inches,* 6 *feet high.*

| | RS. | A. | P. |
|---|---|---|---|
| Masonry, 195 cubic feet, say 200 cubic feet, at Rupees 14 per 100, Rupees 2 extra allowed for lead of material in river bed, ... ... ... ... ... | 28 | 0 | 0 |
| Curb, with lead, ... ... ... ... ... | 0 | 10 | 0 |
| Labor in excavation as above, ... ... ... | 2 | 1 | 9 |
| Shifting scaffold and platform from block to block with loss of time, ... ... ... ... ... | 1 | 0 | 0 |
| Wear and tear of tool and scaffold, &c., say, ... ... | 1 | 0 | 0 |
| | 32 | 11 | 9 |
| Contingencies, at 10 per cent, say, ... | 3 | 4 | 3 |
| Total Rupees, .. | 36 | 0 | 0 |

This does not include filling the core.

It is a great advantage that divers can be dispensed with, both because the number to be obtained is limited, and because they are very subject to fever in the cold weather. The saving of time is also great.

There appears no reason why this tool should not work in deep water, and, if required, in stiffer soils; by building hold-fasts into the walls of the well as resisting points, and using chain tackling to force the machine down, it would probably act in stiff silt. But, doubtless, in that case, a knife-edged curb would be necessary to cut into the soil.

G. R. L.

## No. CCLIX.

# INLAND NAVIGATION AND CHEAP RAILWAYS.

By Lieut. J. M. Heywood, R.E.

*February 13th*, 1869.

Having in the course of my investigations on the subject of the improvements now being made in the navigable ways of France, met with two or three papers on Inland Navigation and Cheap Railways, which appear to offer useful information, I have prepared a short resumé of the results arrived at in them.

The first paper is on Inland navigation by M. Bazin, one of the first Hydraulic Engineers of the day. It appeared in the number of the "Annales des Ponts et Chaussées," for September and October 1867.

Concisely, the opinion laid down is, that railways are useful to efface distances—to transport passengers and costly traffic; that the navigable ways, though imperfect and neglected for the time, must rise to importance, as being the proper channels for the conveyance of bulky unmanufactured goods. The mean cost, according to M. Bazin, of transporting one ton per mile in a Railway is from 0·94*d.* to 1·109*d.* Singularly enough, the former figure exactly agrees with the rate struck from the actual returns of the merchandise carried on the principal lines during the year 1867, the accounts for which were published several months after the date of the paper under consideration.

On Canals, the cost of haulage by men = 0·1567*d.* per ton.

The navigation dues vary from 0·031*d.* to 0·783*d.*, or a total of between ·187*d.* to ·235*d.* per ton per mile.

The cost of haulage by horses = 0·235*d.* per ton.

The navigation dues being the same as before, the total expense is ·266*d.* or ·3133*d.* per ton, according to the class of goods conveyed.

| | | |
|---|---|---|
| On railways the different expenses amount to, ... | | ·5013*d.* |
| Interest of capital expended, ... ... ... ... ... ... | | ·47 |
| | Total, | ·9713*d.* per ton per mile. |

This provides for wear and tear, &c., so that a ton on a railway is moved a mile for a penny, whilst a ton on a navigable way is moved a mile for between $\frac{1}{4}d.$ and $\frac{1}{3}d.$

The second paper is a resumé of a description of a Railway Bridge-of-boats thrown across the Rhine at Maxau, translated from the German by M. Mentz, and printed in the "Annales des Ponts et Chaussées" for 1866.

The discussion about a bridge over the Hooghly led me to examine the article. A bridge costing £16 to £17 a foot might serve as a make-shift till a permanent one could be erected, and further, if light railways are ever extended, some cheap method of crossing rivers must be adopted.

The third paper gives the results of a long paper on Cheap Railways, by M. Ruelle, to be found in the "Annales des Ponts et Chaussées" for July 1868.

It was written to combat the notion that Railways can ever be made so cheap as to supersede the Imperial or Departmental Roads; he proves, in fact, that there is a limit to their construction, and that a very speedy one if they are intended to be remunerative; and that what is called the 4th net-work of railways cannot be executed at a sufficiently low rate to pay.

On the subject of roads, I add a few details from experience which has been confined to Bengal proper. Broken brick is the great material available in most districts for metalling—the earthen road with 6 inches of broken brick wears down in two years if subject to heavy traffic. Now suppose the metalled or macadamised part of a road to be 16 feet wide, and that 9 bricks go to the cubic foot of broken metal, we have—

16 feet × 6 inches × 5280 feet × 9 = 380,160 bricks, at 12*s.* per 1000 = £228, so that the actual cost of materials per annum = $\frac{228}{2}$ = £114 per mile, not including labor.

Even with all the facilities arising from proximity to Calcutta, the Municipality of that town used to pay—

| | £ | s. | d. |
|---|---|---|---|
| Broken brick, including cartage and spreading, at 11*s.* 9*d.* per 100 cubic feet, per mile, .. .. .. | 248 | 0 | 0 |
| Add to this (42,240 cubic feet) for rolling by bullocks, at 9*d.* per 100 cubic feet, .. .. .. .. | 15 | 16 | 10 |
| 84,480 superficial feet binding cement, spreading, &c., at 9*d.* per 100 superficial feet, .. .. .. | 31 | 13 | 8 |
| Total, .. .. | £295 | 10 | 6 |

not including supervision. This sum spread over the two years the road lasts = £147 15*s.* 3*d.* per annum.

Take a new road :—

| | Metalling. |
|---|---|
| The double soling over 84,480 superficial feet absorbs 464,640 bricks ; these, at 12 per 1000 = £278, .. .. .. .. | 295 |
| Soling material alone (not including the labor of fixing), .. | 278 |
| | 573 |

I do not believe that an earthen road can be macadamised in many districts of Bengal proper under £700 a mile ; and its repairs, if the traffic is heavy, will at least rise to £120 per annum per mile. Where stone is easily procurable and labor cheap, as for instance on the Grand Trunk road at the Burrakur, the following rate may serve as an example :—

For 100 superficial feet of new road (6 inches of metal over pitching).

| | s. | d. |
|---|---|---|
| Rubble for pitching, .. .. .. .. .. | 5 | 0 |
| Labor for do., .. .. .. .. .. | 0 | 6 |
| 50 cubic feet of metal, .. .. .. .. | 4 | 0 |
| Spreading, .. .. .. .. .. .. | 0 | 6 |
| Value of binding cement, .. .. .. .. | 0 | 9 |
| Spreading, .. .. .. .. .. .. | 0 | 3 |
| Consolidating,.. .. .. .. .. .. | 3 | 0 |
| | 14 | 0 per 100 s. ft. |

Remembering that 84,480 superficial feet go to the mile, the cost is £591 per mile, not including the supervision.

Deducting the pitching, the rate becomes 8*s.* 6*d.* for the metal ; this requires renewal every four years, or an expenditure of £359 spread over that space of time, viz., £89 a year.

The annual maintenance, of the roads of Lower Bengal varies, therefore, between £150 and £90, or a mean of £120 per annum per mile.

As roads increase, so will this alarming annual charge grow, till at last the whole grant for the purpose will be absorbed in repairs.

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RAILWAYS *versus* CANALS. (*Annales des Ponts et Chaussées*, 1867. *M. Bazin*.

Railways efface distances and bring nations close together, but for the conveyance of heavy merchandise, they are not so economical as water carriage.

Canals only require a moderate sum for maintenance. Railways require a numerous staff and costly materials; the expense of their maintenance can never descend below £386 per mile.

The price of a manufactured article includes evidently the cost of the transport of the materials, and this is so much the greater in certain cases, in proportion as the weight of the raw materials exceeds that of the manufactured: thus the production of a ton of iron requires the transport of many tons of coal and mineral for a long distance, so that the transport of materials at a reduced price is, for the great industries, a very important matter.

*Haulage on Railways.*—The mean cost at the present time of the carriage of 1 ton per mile is, on the French Railways, 94*d.*; this is a very considerable reduction on the tariffs in force previous to 1847, and even up to 1854.

This reduction results:—

1*st.* From the improvement of the means of transport, viz., improvements effected in the roadway of increase of power in the engines.

2*nd.* From the completion of the great net-work of railways, by which full developement has been given to the traffic, all important places being connected.

It cannot, however, be expected that further improvements in the rolling stock and permanent way will influence the price much, and the increased developement in the direction of branch lines does not bring a proportional traffic, so that the limit of the lowering of tariffs has probably arrived.

The cost of carriage on a Railway consists of two distinct parts :—

*1st.* The actual cost of conveyance.

*2nd.* The interest of the money spent on the line.

The expenses under the 1st head are—

| | |
|---|---|
| For Superintendence (central administration, "personal" of the trains, stations, &c.), .. .. .. | 0·133*d.* |
| For traction (coals, firemen, store keepers, repairs of engines, &c., not including the interest of the "material"), .. .. .. .. .. .. | 0·175 |
| Service of the road (maintenance and inspection of the road, repairs of buildings, &c.), .. .. .. | 0 0705 |
| Total per ton per mile, .. | 0·321*d.* |

This result is a little too low, it having been arrived at by calculating that Passenger and Luggage Trains cost alike; this is the case on some lines where the passengers and goods are conveyed in the same train, but on the long important lines, the passenger and goods are carried separately. The special trains for the latter are more expensive than those for the former; thus an engine of a passenger train consumes 25 lbs. of coal per mile, that in a goods train uses 45 lbs. (35 to 55), so that the above cost per ton is raised to 0·376*d.* per ton. The interest and deterioration fund is not included in this figure—it amounts to about 0·1253*d.* per ton per mile.

We have, therefore—

| | |
|---|---|
| Working expenses, Traction, ... ... ... ... | 0·1567*d.* |
| Interest, and replacing material, ... ... | 0·2663*d.* |
| Service of the way, ... ... ... ... | 0·0783*d.* |
| | 0·5013*d.* per ton per mile. |

This amount does not include the interest and paying off of the capital employed on the construction of the line.

*Haulage on Canals.*—On canals there is not the same uniformity; the methods of traction are numerous, and the cost of transport varies accordingly. The haulage on canals is effected by men and horses, that on rivers is now performed by steam power, to the exclusion of all other methods, when practicable.

*By men—*

| | |
|---|---|
| Traction, properly so called, costs ... ... | ·0783*d.* per ton per mile. |
| Interest, sinking fund, cost of the maintenance of the boat, ... ... ... ... ... | ·04701*d.* „ „ |
| Total, ... | 0·12536*d.* „ „ |

If the boat makes its return journey empty, as is generally the case, this is raised to 0·1567*d.* per mile. The method of towing by men is thus cheapest, but the slowest, as two men, one on either bank, can only draw a 148 ton boat for a distance of between 7 and 8 miles a day.

*By horses.*—Haulage by horses is dearer, but twice as rapid (12 to 19 miles a day), and costs

| | |
|---|---|
| Traction, properly so called, ... ... ... | 0·1109*d.* per ton per mile. |
| Pay of the Captain of the boat, salaries of the boat-men, ... ... ... ... ... | 0·04701*d.* „ „ |
| Interest, sinking fund, repair of boat, ... | 0 04701*d.* „ „ |
| Total, ... | 0·20492*d.* „ „ |

When the boat returns empty this becomes 0·235*d.* per ton per mile.

*Haulage on Rivers.*—Towing by a submerged* chain is the most economical. The towing boat is fitted with pullies set in motion by steam, over which a chain of indefinite length, resting otherwise on the bottom of the river, is passed; the boat can thus tow many thousands of tons, for distances varying between 20 and 25 miles a day.

The price per ton per mile is on the Lower Seine, between Paris and Rouen, ascending 0·1567*d.*; descending 0·0628*d.*

On the Upper Seine, between Paris and Montereau, ascending 0·282*d.* The descent is make without assistance, but costs something. On the Upper Seine, the navigation is intermittent and conducted by flushes, so that it is expensive; the construction of movable dams will probably reduce the rate.

*Carriage of Merchandise requiring a more rapid transit.*—The cost of transporting such goods is difficult to settle. On many of the navigable ways rapid means of conveyance (25 to 30 miles a day) are provided; it

* *See* No. CCIII. of these Papers.

very often happens that the boat is not completely loaded; the merchandise also requires more care, involving greater expense for maintenance, insurance, &c. The rate varies between 0·235*d.* and 0·470*d.* per ton per mile. On canals, the employment of steam boats is generally of little advantage, owing to the time lost at the locks, as well as the small tonnage capacity of the boats compared with the ordinary ones, but on rivers they compete with railways in speed, and are useful.

The rates given above would seem small if it was not a fact that on the great lines of navigation the cost of the transport of merchandise varies between 0·1567*d.* and 0·3134*d.* per ton per mile; on the canals, "du nord," the freight of coals is as low as 0·2037*d.* (not including the navigation dues), but this is hardly remunerative.

Comparing the different items of cost of transport on railways and canals, &c., we find that the former is double of the latter, as the following considerations will show:—

*Traction properly so called.*—Railways have arrived at their limit in this matter; the traction has been an object of continual study for 30 years, and it now constitutes only one-fourth of the total cost of the carriage.

*Administration.*—The charge under this head is 3 or 4 times as great on railways as on navigable ways; this is easy to understand when the expensive and complicated administration of the former is compared with that of the latter.

*Cost of materials.*—A boat costs a few hundred pounds; carries as much as a complete train, whose value is not less than £8,000; and requires a tractive power incomparably less; the disproportion is too great to be compensated by the greatest increased speed of the train. In comparing the two ways, it is not sufficient merely to place the cost of the traction (so called) of the perfect railway, by the side of the (perhaps) incomplete canal; by doing so the most important elements are left out of account; the low price of navigation must always continue in consequence of the simplicity of the means employed, compared with the excessive complication connected with the working of railways, and the enormous amount of capital expended.

To compare the two, therefore, we must consider the navigation dues on the one side, and the interest and paying off of the capital on the other.

*Navigation dues.*—On rivers they only rise to ·0155*d.* or ·0311*d.* per ton per mile. On canals they are ·031*d.* and ·0783*d.*, according to the different classes.

*Interest of capital expended on railways.*—This item is very variable on different lines; but as a mean, the rate is 0·47*d.* per ton per mile.

At the present time, everything is in favor of the railways; the net-work is very complete, and in the hands of a few large companies; whilst the waterways are without branches, disconnected from one another, paralysed by gaps, the management of each small section in the hands of separate companies, and subjected to heavy navigation dues.

As an instance of a competition between a Railway and a Canal, may be mentioned the case of the Northern Railway of France and the parallel Canals. The Northern Railway has an exceptional position, passing through the richest part of the country, without any unproductive branches; it connected Mons with Paris, this distance being only 155 miles, whilst the water-way is 217 miles. Special trains by the former bring down 400 tons at a cost of 7*s.* 3·36*d.*, whilst the boat rate is only 5*s.* 2·4*d.*, or 0·282*d.* per mile, of which ·0783*d.* is for navigation dues; this rate it is expected will be further reduced to 0·235*d.*

The Canal would probably have succumbed to so powerful a line as the Northern railway; but the latter, instead of meeting a body of capitalists, has had to contend with a population of boatmen, who in numerous cases live with their families in their boats, and who thus fighting, *pro aris et focis*, sustain the contest under more favorable conditions, and the traffic has continued to increase. Whether the railway under such circumstances makes the coal traffic pay is almost impossible even for the company to find out; it is very probable that the magnificent traffic in other directions compensates the loss; at present the cost of the carriage of the coal is the same, no matter what the distance traversed may be. Up to 1863, the traffic on the canals gained on the railway, owing to the lowering of the navigation dues on the former in 1860. So that the present low price was fixed in order, as the Director's report, "to dispossess the canals" of the traffic of which they monopolise "the greatest part."

Competition is not, however, the only thing which compels the lowering of a tariff. The article of merchandise may not pay if subjected to too great a charge for carriage; the maximum price of transport will therefore find its level on purely commercial grounds. Again, return wagons often

travel empty; to utilise these, freights at low rates are invited in order to diminish some of the inevitable expenses. These causes of reduction apply to both methods of transport. Deducting the interest of capital expended, the price of carriage on railways is from 0·47*d.* to 0·55*d.* per ton per mile, so that 0 628*d.* per ton per mile may be considered remunerative, and this is generally the reduced tariff for special articles; those below 0·47*d.* are very rare, and are nearly all for return traffic, such as manure from Paris, &c. All these rates are, however, exceptional, and only apply to long distances, the mean for each company, taking the whole traffic is from 0·94*d.* to 1·109*d.* per ton per mile. The competition of canals and railways may lower the tariff of merchandise in some cases, but it forces an additional price on the railways in other cases; and canals have little influence on the highly priced merchandise, which constitutes the chief source of wealth to the railways.

Railways can lower their tariff to 0·47*d.*, canals to 0·235*d.*; the railways therefore make up by an additional rate on one description, what they lose by carrying another. Canals, by carrying the raw materials at low prices, develop the industries already existing in the districts they pass through, and establish new ones.

| | | | |
|---|---|---|---|
| For 1866 the Northern railway carried | 8,872 | tons of merchandise | per mile. |
| „ mean for the whole of France | 4,753 | „ | „ |
| „ „ Swiss railways | 2,773 | „ | „ |
| For 1867 the Northern railway carried | 8,060 | „ | „ |

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## Bridge-of-Boats for a Railway across the Rhine, near Moscow.

*(Annales des Ponts et Chaussées,* 1866.*)*

Breadth of the Rhine, 787·2 feet.

Greatest known rise above lowest known level, 21·94 feet.

The highest level has not been attained since 1817; the lowest level was reached in 1858, and has only occurred once, so that for all practical purposes a much less difference will suffice, this is calculated to be 16·73 feet.

The greatest mean velocity of the Rhine, taking the highest of these two figures, = 6·88 feet per second, and the discharge under the same circumstances 161,131 cubic feet per second. The discharge during the flood stage of the river = $3\frac{1}{2}$ times that of the mean stage, and $12\frac{1}{3}$ times that of the summer stage.

The deepest channel shifts from one bank to the other once in two or three years, so that two passes are required in the bridge to accommodate the navigation.

The number of times the old bridge-of-boats was opened to allow the passages of steamers, &c, was.

In 1862 = 896 1863 = 1,020 1864 = 920

In December and January, the bridge is opened once every two days; in February once a day; in March, April, August, September, October, and November, three times a day; in the other months nearly four times a day.

Allowing half an hour for the opening and closing, it would appear that the trains will be delayed from a half to one hour in winter, and two hours a day in summer. When the ground ice descends the Rhine, the bridge is removed—this occurs from twice to four times each winter.

The bridge consists of—

| | |
|---|---|
| The bridge proper, ... ... ... ... | = 767·52 feet. |
| And the approaches, each 211·23 feet, ... ... | = 422·46 „ |
| Total, ... | 1,189·98 „ |

The bridge proper is composed of 12 bays resting on 34 pontoons—

| | |
|---|---|
| 2 bays near the bank, each 67 24 feet ... ... ... | 134·48 |
| 6 bays capable of being opened for the passage of ships— | |
| 2 each, 68·88 ... ... ... ... ... | 137·76 |
| 2 „ 41·00 ... ... ... ... ... | 82·00 |
| 2 „ 68 88 ... ... ... ... ... | 137·76 |
| 4 bays in the middle, each 68·88, ... ... ... | 275·52 |
| Total, ... ... | 767·52 |

The approaches rest on trestles placed 19·22 feet apart.

The inclination of these approaches at the lowest water level (since 1857) is 3·5 in 100.

Do. 9·97 feet higher, is level.

Do. 16·73 above the low water level is 3·29 in 100.

At the mean height of the river the inclination is 1·62 in 100.

The breadth of the bridge is as follows—

| | | |
|---|---|---|
| | 11·48 | feet for the railway. |
| | 13·77 | „ for a carriage road up-stream. |
| | 13·77 | „ „ „ down-stream. |
| Total, | 39·02 | feet. |

The pontoons are of wood—

| | | |
|---|---|---|
| 73·8 feet long, ... ... | | |
| 15·088 „ broad, ... ... | | For the bays near the banks. |
| 4·59 „ clear height, ... | | |

and

| | |
|---|---|
| 65·6 feet long, ... ... | |
| 12·136 „ broad, ... ... | For the other bays. |
| 4·59 „ clear height, ... | |

In a bay, the pontoons are placed 11·81 feet a-part, but each bay is only 4·92 feet from its neighbour. Each pass, of which there are two, consists of three bays—

| | |
|---|---|
| One 68·88 feet .. ... ... | 68 88 feet. |
| „ 41·00 „ ... ... ... | 41·00 „ |
| „ 68·88 „ ... ... ... | 68·88 „ |
| Total, ... | 178 76 „ |

The whole work was completed in 12 months, and cost

| | £ |
|---|---|
| Approach on the left bank, .. .. .. .. | 350·51 |
| „ right bank, .. .. .. .. | 351·09 |
| Bridge proper, .. .. .. .. .. .. | 12,404·90 |
| Total, .. .. | £13,106·50 |

or for the bridge proper, £16 3*s*. 2·4*d*. per foot.

„ approaches, £1 13*s*. 2·4*d*. per foot.

The locomotive is made especially for the work, and weighs, with its tender, 15 tons; it can develope a force equal to between $\frac{1}{8}$ and $\frac{1}{10}$ of its weight. This force is sufficient to move

| | tons. |
|---|---|
| On a horizontal plane, .. .. .. .. .. | 370 |
| On a slope of 1 in 100 .. .. .. .. .. | 150 |
| „ 2 „ 100 .. .. .. .. .. | 55 |
| „ 3 „ 100 .. .. .. .. .. | 33 |

During the greater part of the year the locomotive can draw the maximum load, and make 12 journeys a day each way, which, at 75 tons per journey, gives a total of 780 tons each way, or 1,560 tons in all for the day trips.

CHEAP RAILWAYS. (*Annales des Ponts et Chaussées*, 1868. *M. Ruelle*)

The following four classes have only a single line :—

| Group. | Cost of estimating and personnel. | Purchase of land. | Earthwork, &c. | Bridges, &c. | Way and fixed material. | Station and guards' houses. | General expenses and interest during construction. | Total per mile. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | £ | £ | £ | £ | £ | £ | £ | £ | |
| First, .. | 558·2 | 2028·2 | 455 7 | 3787·7 | 3654 5 | 1808 5 | 1475·4 | 17,869 | Very difficult country. |
| Second, .. | 534·6 | 1295 3 | 3661·5 | 1927·9 | 3570 4 | 1931·3 | 1162·8 | 14,084 | |
| Third, .. | 680·6 | 1339·2 | 2598·3 | 1477 2 | 2918·7 | 1032 8 | 803·7 | 10,850 | |
| Fourth, .. | 386·4 | 1281·8 | 1481·4 | 2640·9 | 1822·8 | 1088 5 | 506 0 | 6,831 | Very easy. |

| | £ |
|---|---|
| On a line where the rails can be laid on the level of the ground, and where the earthwork, cuttings, bridges and other work do not cost, .. .. .. .. .. | 1,000 |
| And where the fixed material, stations, guard houses, &c., cost, .. .. .. .. .. .. .. .. | 1,800 |
| And where preliminary estimates, land and interest, .. | 1,200 |
| Per mile, total, .. | £4,000 |

the receipts must amount to at least £770 per mile. If the railway pass through a mountainous country, and costs, with its rolling stock £10,300, the expenses can only be covered by the receipt of £966. For a railway costing £12,880 per mile, the receipts must be at least £1,160 per mile.

| | £ | |
|---|---|---|
| Cost of French railways, former net-work, .. .. | 29,017 | per mile. |
| New, .. .. .. .. .. .. .. | 28,162 | „ |
| Belgium, .. .. .. .. .. .. .. | 19,323 | „ |
| Austrian, .. .. .. .. .. .. .. | 18,679 | „ |
| Prussian, .. .. .. .. .. .. .. | 16,940 | „ |
| Other German States, .. .. .. .. .. | 15,587 | „ |
| Swedish, .. .. .. .. .. .. .. | 6,650 | „ |

J. M. H.

# No. CCLX.

## THE PENNAIR BRIDGE—MADRAS RAILWAY.

*By* EDWARD W. STONEY, ESQ., *Resident Engineer, Madras Railway.*

THE Pennair bridge is 1,680 feet long between abutments, this distance being divided into twenty-four openings, of 64 feet clear span each, by masonry piers 6 feet thick; twelve being founded on solid masonry, and the remaining eleven on brick wells.

The superstructure consists of wrought-iron plate girders in pairs connected transversely by bracing frames, each pair being 139 feet 10 inches long, and continuous over two openings; it carries the Madras Railway (N. W. Section) over the Pennair river, at a point close to the village of Jootoor, about 6 miles from Tadputri station, and 234 from Madras.

The Pennair river rises in Mysore, 150 miles north-west of the bridge, close to the village of Danaroy Droog, comprising in this length a catchment area of about 4,500 square miles. During the greater part of the year there is apparently no water in it, but a plentiful supply is always to be met in the sand forming its bed, at from 1 to 4 feet below the surface, according to the time of year. During the wet season, a large volume of water flows through the bridge, the moonsoon floods usually rising to a height of 6 or 8 feet above the lowest point of the river bed. Extraordinary floods, however, have been known to reach the level of pier cut-water tops, thus giving a depth of some 13 feet of water. Rail level had to be fixed with reference to the latter, which rendered a heavy embanked approach for some distance on the south side necessary.

The river gradually narrows to the site of the bridge, where it has a breadth of some 1,550 feet, with a tolerably steep bank on the north side.

The nature of its bed is very variable, as will be seen by a reference to general sectional elevation, *Fig.* 1, *Plate* IV. Starting from the south abutment, a bed of clay is first met, diminishing from 5 feet in thickness there, to zero at the fourth pier, where it disappears; underlying this, comes a mixture of gravel, with clay and kunkur nodules, about 4 feet thick; beneath which again, is a layer of sand, and finally hard dark-green kunkur. From the 4th to the 23rd pier, consists, for a depth of from 12 to 20 feet, of fine sand, interspersed with layers of clay and vegetable matter, underlayed by compact red clay and hard kunkur, the former being replaced by dark green, and black, mud or clay, on the north side.

*Foundations.*—The foundations of the abutments and six piers on either side are of solid masonry, of the form and dimensions shown in *Plate* V. *Figs.* 1 and 2; being 39 feet long, and 12 feet wide at the bottom, diminishing by steps to a width of 8 feet at the fair work, and laid at depths of from 10 to 15 feet below the river bed.

In order to lay them, a space round each pier, 48 feet long by 20 feet wide, was enclosed by jungle wood piles, 20 feet long and 9 inches average diameter, shod and hooped with iron; these were pitched 6 feet 6 inches apart at the sides, 8 feet at the ends, and driven to a depth of 20 feet, by a monkey engine—at the back of these, 3-inch mango planks, 17 to 20 feet long and 2 feet 6 inches wide, were placed, and behind them a foot of well rammed clay puddle was put. The enclosure thus formed, was then excavated by coolies, while the interior was kept free from water by *picottah* pumps, 16 to 20 being required for each pier, arranged as shown in *Plate* V., *Figs.* 1 and 4.

As soon as the excavation was completed and a hard bottom reached, the foundations of coursed rubble lime stone masonry, laid with kunkur lime mortar were put in, and carried up to the heights shown in the general section, *Plate* IV., *Fig.* 1.

The central piers, eleven in number, are built on well foundations: by this means cofferdams, and the greater part of the pumping necessary in the solid foundations was avoided; each foundation consists of 14 wells, arranged as shown in *Plate* V., *Figs.* 2 and 3, with the least possible space between them.

These wells are cylinders 9 inches thick, 4 feet internal, and 5 feet 6 inches external, diameter, built on wooden curbs, with well burnt radial

bricks, 9″ × 4½″ × 3″; the exterior being bound with straw rope closely coiled, for the double purpose of excluding sand and strengthening them.

The mode of putting in these foundations was as follows:—

A rectangular space, 48 feet by 15 feet, was excavated in the sand till water was reached, which was about 3 feet 6 inches below the surface in the dry season; the well curbs were then placed in position on the bottom of the excavation, after which about 5 feet in height of each well were built; these, being then roped, were ready for sinking, which was performed by men working with baskets at each in the usual manner, a fresh length of brickwork being added as required to each well, till the whole were sunk as deep as possible.

They rested in all cases on a hard stratum of clay or kunkur, and were driven to depths varying from 8 to 15 feet below the river bed, their average depth being 11 feet.

All wells composing a foundation having been sunk, were filled with hydraulic concrete—composed of 1 part lime, 2 brick dust, and 4 of broken stone—first mixed dry and afterwards thoroughly tempered with water, in quantity sufficient to make the chunam and brick dust into a stiff mortar; these proportions, after numerous experiments with the local lime and clays, the writer found to give the best results; the concrete so formed set under water in three days, and became excessively hard after a month's immersion.

In order to prevent the lime from washing out, the concrete was put into a gunny bag, which was then lowered into the wells, mouth downwards, by ropes attached to its bottom corners: as soon as the mouth reached the bottom, it was opened by means of running strings attached thereto, and the contents dropped out as the bag was drawn up by the ropes previously used to lower it, being again ready to be refilled and discharged as before.

The interstices between the wells were cleared up for a depth of 3 feet below water level, and similarly filled with concrete; stakes were then driven a foot away from the outer edge of the wells, and a row of mango planks placed behind them; a few picottah pumps were then erected (generally six sufficed) and the water lowered, when the wells and concrete were all neatly levelled off to the heights shown in *Fig.* 1, *Plate* IV., at an average of 4 feet below river bed, and uniform for all piers. Flags 6′ × 3′ × 6″ were then laid diagonally over the wells and concrete, and

upon these was built two stepping courses, 9 feet thick, of the form and dimensions shown in *Plate* V., *Figs*. 2 and 3.

*Fair work*.—The fair work of abutments and piers consists throughout of the best rubble masonry, composed of light gray lime stone laid with kunkur lime mortar, in courses of varying thickness, averaging at the bottom 1 foot, and gradually diminishing to 6 inches at top; the stones of these courses are all well bedded, with joints dressed square back from the face for 4 inches, and comprise among them a large proportion of bonds 2 to 3 feet long; the hearting being carefully laid in mortar, and afterwards grouted so as to insure the filling of all vacuities.

The piers are each 7 feet broad at base, diminishing to a width of 6 feet at top by uniform batter of 6 inches on each side; the ends being formed into triangular cut-waters terminated by a triangular pyramid, stepped from 5 feet below, to within 2 feet of the pier tops. They measure 29 feet in length, being built for the reception of a 2nd set of girders, should it hereafter become necessary to double the line; their average height from the river bed to the under side of girders is about 20 feet. Girder stones $6' \times 2' \times 1'$ each, in two pieces 3 feet long, are carefully bedded and dressed truly level; lewis bolts, bedded in each, secure the girders thereto.

The abutments are built as shown in *Plate* IV., *Fig*. 2, their wings and parapet walls, as well as the piers, being coped with dark blue lime stone, which contrasts well with the light gray of their mass; the whole work is neatly pointed, and a chisel draft $1\frac{1}{2}$ inches wide, dressed on all exposed corners.

*Superstructure*.—The superstructure for a single line of railway, is formed of wrought-iron plate girders, arranged in pairs, 8 feet apart, from centre to centre, connected together by means of seven plate, and twelve cross bracing, frames, disposed as shown in *Plate* VI., *Fig*. 2; each pair, with its frames, &c., comprises one set 139 feet 10 inches long, continuous over the two openings spanned by it.

The roadway is laid with double I rails, 75 lbs. to the yard, fished at the joints, and supported by cast-iron chairs, secured to teak sleepers $12' \times 12'' \times 6''$, placed 2 feet $10\frac{1}{2}$ inches apart. These sleepers rest upon the top flanges of the girders, and are secured thereto by four dog bolts in each, as shown in *Plate* IV., *Fig*. 2.

*Girders*.—The girders composing each set are of I section, 139 feet 10 inches long by 4 feet deep, and consist of a similar top and bottom flange,

each formed of two 12″ × ⅝″ plates connected by two ∠ irons, 3½″ × 3½″ × ½″ with the web, which is of uniform section (3′ 9″ × ⅜″) throughout, the whole being firmly united, by means of suitable cover and joint plates and ¾-inch rivets of 4-inch pitch; the flanges at the centre being strengthened by an additional plate 16′ × 12″ × ⅝″.

Each girder is sent from England and arrives where it is to be erected in five sections, of the following lengths, viz. :—

| | | |
|---|---|---|
| 2 of 21 feet 4 inches | | abutment pieces. |
| 2 „ 30 „ | | intermediate „ |
| 1 „ 37 „ | 2 „ | forming the centre, marked A on *Fig.* 2, *Plate* VI. |

Thus, in erecting, four through joints have to be made in each girder, or eight in each set of two.

For the joints A in the flanges, cover plates 6′ 4″ × 12″ × ⅝″, secured by four rows of ¾-inch rivets (18 in each) are used, while for the ∠'s and web joints of the same ∠'s, covers 2′ × 3½″ × 3½″ × ½″, and T bars 6″ × 3″ × ⅜″ respectively, are used, secured by ¾ inch rivets disposed as shown in *Figs.* 5, 6, 7 and 8, *Plate* VI.

For all other plate joints, [*Figs.* 13, 14, 15, 16, *Plate* VI.,] cover plates 3′ × 12″ × ⅝″ are used; whilst for the remaining ∠ iron joints, [*Figs.* 9, 10, 11, 12, *Plate* VI.,] plate covers 2′ × 12″ × ⅜″ with ∠ cover 2′ × 3½″ × 3½″ × ½″ are used, secured by ¾-inch rivets.

Each pair of girders forming one set, are joined transversely by bracing frames, arranged as shown in *Fig.* 2, *Plate* VI.; these are of two sorts, plate bracings *Fig.* 3, *Plate* VI., formed of ¼-inch plate, stiffened by two angles, ∠ 3″ × 3″ × ½″ all round, and two pairs of intermediate vertical T iron struts 6′ × 3″ × ⅜″; and cross bracings, formed by a framing composed of a pair of ∠'s 3″ × 3″ × ½″ separated by filling pieces, and braced by T iron struts, 5″ × 3″ × ⅜″ securely rivetted to corner gusset plates, as shown in *Fig.* 4, *Plate* VI.

The 8 pieces of girder and 19 bracing frames forming each set of girders, are joined together by 2,624 rivets, distributed thus:—

| | |
|---|---|
| 8 through joints, each 206, ... ... ... | = 1,648 |
| 19 bracing frames each 44, ... ... ... | = 836 |
| 6 bed plates, ... ... ... ... ... | 140 |
| Total, ... | 2,624 |

The weight of each set of girders complete is about 37 tons, distributed thus:—

| | Ton. | Cwt. |
|---|---|---|
| 1 Pair of girders, exclusive of covers, &c., ... | 27 | 15 |
| Cover plates for girders and fittings, ... ... | 3 | 8 |
| 12 Open bracing frames, ... ... ... ... | 3 | 10 |
| 7 Solid " ... ... ... ... | 2 | 10 |
| | 37 | 3 |
| The sleepers and permanent way add to this, ... | 11 | 7 |
| So that the total dead load ... = | 49 | 0 |

per 140 feet, or 7 cwt. per foot run of roadway, equivalent to $3\frac{1}{2}$ cwt. per foot run on each girder of the pair forming one set. The greatest running load does not exceed 10 cwt. per foot run each girder, so that the maximum load to be sustained is about $13\frac{1}{2}$ cwt.

*Mode of Erecting.*—In order to build the girders, a length of about 300 feet of embankment behind each abutment, was levelled to a height of one foot above girder stone, this area allowing four sets, two abreast, to be set up on it, arranged as shown in *Fig.* 3, *Plate* VII.

Upon the arrival from Madras by railway of the girder sections, the trucks conveying them were shunted into a siding along side the bank, previously levelled for their reception; and an inclined plane, formed of rails supported by a temporary sleeper staging, was laid from the wagon to the bank. Two ropes were attached to the piece of girder to be unloaded, which was then hauled up by men at each rope; in this way the pieces weighing from 3 to 5 tons each were rapidly unloaded, and then drawn on rollers to the position they were to occupy, in the sets about to be put together.

The ten pieces or sections forming a set having been rolled into approximate position, were each turned up and put standing upon transverse sleepers, placed about 3 feet apart; the bracing frames of each of the four portions about to be put together, were then secured by means of screw bolts to the girder sections forming them; and this being done, each portion was brought into proper line and level with the adjoining ones, by means of wedges driven between the sleepers on which they rested, and the bottom flanges.

Joint filling pieces, cover plates, &c., were now put on, and the plates &c., of all portions to be rivetted, brought as close together as possible by means of screw bolts, any holes requiring it being at the same time drifted and rymed; all having have been thus properly prepared, rivetting began, which was executed exclusively by native workmen, both well, and with, I think, uncommon rapidity.

The first pieces of girder arrived on the ground on the 22nd October, 1868—setting up was begun on the 24th, and by the 24th December all the rivetting was completed, as well as 8 sets rolled; and the whole would have been rolled and in place by the end of December, had the masonry of all piers been ready for their reception. In these two months, there were only 55 working days, during which time 12 sets of girders were unloaded, set up, and joined together by some 34,000 rivets, as well as a large portion of them rolled into place. In order to estimate the quantity of work done, it may be stated that the material above-mentioned comprised 120 pieces of girder, 228 bracing frames, as well as all cover plates, rivets, and other fittings, forming together some 1,680 lineal feet of girder, weighing over 370 tons.

Four sets of girders were constantly worked at by four sets of men; one of which unloaded and set up the girder, another fitted and screwed it up, ready for the rivetters; the third rivetted; and the fourth rolled away girders as rivetted.

In this way the rivetters were kept busy, and a pretty constant out-turn of finished worked kept up; as the moment a set was rivetted, it was removed by the rolling gang; and whilst the rivetters went on with a set previously prepared by gangs 1 and 2, the same gangs set up and prepared for rivetting a fresh set in lieu of that rolled.

Some of the rivetting gangs put in as many as 200 to 220 rivets daily, with only 2 per cent. bad; and the number of defective rivets, which had to be cut out and replaced was only 6½ per cent. of the whole number driven. Considerable difficulty was experienced in getting rivetters and good coolies (the villagers being afraid of the heavy weights to be moved), as the bridge was situated in a very out of the way place, and in a most feverish locality during November. Many men died of fever. On an average some 70 rivetters daily were employed.

The whole of the rivetting, &c., was executed departmentally under the writer's immediate supervision, assisted by a European inspector; all the small tools, such as snaps, drifts, &c., being made and repaired on the works by native smiths.

Considering the difficulties encountered, the results obtained were, it is believed, very satisfactory, and speak highly of the capabilities of native workmen when properly organized and superintended.

*Rolling girders.*—The method to be now described by which the girders

were put in place on the piers, differs considerably from that usually pursued, and possesses some points of interest and novelty.*

Instead of constructing timber platforms under each opening, (as is usually done,) upon which to erect and rivet the girders designed to span them, these were built as previously described on the bank behind each abutment, in lengths sufficient to span two openings; and then rolled forward across opening after opening till they reach their desired destination, when they were lowered by means of screw jacks on the girder stones prepared for their reception.

In order to roll a set of girders, it is necessary upon the completion of of rivetting, to lift it with screw jacks about 18 inches above the transverse sleepers on which it rests, and affix to the lower flange by means of rail straps, and dog bolts [*Plate* VII., *Figs.* 4 and 5]. 75 lbs. double headed rails laid flat, secured at the joints by fish plates, having bolts with their heads countersunk on the inside [*Plate* VII., *Fig.* 5]; these joints have to be so arranged as to keep clear of cover plates. Filling pieces are put inside the rails at intervals so as to give them an even bearing; the end rails are allowed to project some 12 feet, so as to relieve the girders from the strain due to overhanging as early as possible.

Three platforms of sleepers disposed as shown in *Plate* VII., *Figs.* 1 and 2, were now made, and on these, directly under the rolling rail, 12 cast-iron rollers (*Fig.* 4), arranged in groups of four, were placed, and secured thereto by dog spikes; upon these the girders were then lowered. Four similar rollers, secured to sleepers, having been placed on the girder stones of the abutment and piers to be passed over, it only remained to fix the hauling tackle, which consisted of a double purchase crab winch, secured to sleepers resting on the top flanges over the centre of the girder; a pair of large double blocks, the one **A** attached to a bracing frame, [*Fig.* 1, *Plate* VII.,] in front of the girder, and the other, **B**, resting on top of the second pier forward, on which it was prevented from sliding, by means of rope and tackle fixed round the next forward pier, arranged as shown in *Plate* VII., *Figs.* 1 and 2; the small pair of double blocks (*a b*) being used to take up any slack caused by stretching of rope, and thus keep the block **B** always in the same position.

Through these blocks **A, B,** was passed a 6-inch Manilla rope, one end

* *See* Nos. CXXXV. and CLX. of these Papers.

being secured round the 2nd sheave $x$ of **A**, while the other end, after taking a couple of turns round the crab barrel, was passed back to two men, who coiled it down as fast as it was wound in on the sleeper platform behind the crab.

Every thing being now in readiness, a man was stationed at each pair of rollers to tighten up the rail-dog-bolts as they rolled over, grease the roller axles, and attend to them generally. Twelve men were put to the crab and rolling began; the rate of rolling is about one foot per minute provided no delays occur, but owing to the time taken up in shifting tackle, which has to be done every two openings, and the occasional delays caused by breaking of rails, rail straps, and loosening of dog-bolts, the average rate of progress does not exceed four to six openings a day, or a distance of 420 feet in nine working hours.

As soon as a girder has been rolled over two openings, *i.e.*, up to the double block **B**, this has to be shifted with its tackle two piers forward, the 6-inch rope re-rove, and the process of rolling just described repeated. As soon as the girder has been rolled to its desired position, three pairs of strong sleepers, 12′ × 12″ × 6″, are fastened by dog-bolts to the top flange at the ends and centre; while under these, and resting on the pier, are placed three pairs of stout traversing screw jacks, by means of which the girder is first lifted in order to take out the rollers, and this being done, the rails used for rolling are dropped off and the girder lowered, and traversed into exact line on the girder stones.

During the whole time of rolling, lifting and lowering, packing pieces and wedges were kept on the piers and close under the girders, so that if a screw jack or roller broke, the greatest distance a girder could fall would not exceed half an inch.

The method above described of putting these girders into place is thought by the writer to be a very good one; being cheaper, safer, and more rapid than the ordinary way of rivetting on staging.

1*st*. *Cheaper*.—Since in the ordinary method, timber staging is required for the rivetting, which becomes very expensive with high piers; while by rolling, this is avoided, and the system is equally applicable to bridges with high or low piers.

2*nd*. *Safer*.—As the staging (upon the stability of which the safety of the girders, till rivetted, depends) is liable to be injured, and swept away by floods, or even set on fire by the careless dropping of hot rivets; while for

rolling, the girders are built on the embanked approaches required for the railway.

3rd. *Quicker.*—Since in the ordinary method, the erection of girders is dependent on that of staging, which (particularly if the piers are high) can only be put up for a couple of openings at once, and then shifted forward after the completion of the girder thereon; whilst if the girder be rolled into place, provided sufficient labor can be obtained, the fitting, rivetting, and rolling, of four or even six sets of girders behind each abutment can proceed simultaneously.

In the Pennair bridge, as previously described, four sets only were kept going, as there was great difficulty in procuring labor; the site being excessively feverish and isolated.

The rolling system has been in use on the Madras Railway for some years, and the girders of a fine bridge of forty 64-feet spans, carrying the N. W. Line over the Chittranutty river, were so placed about a year ago; so that the economy and practicability of the system have been well tried. It has also been applied with advantage to the placing in position of girders of much larger span than those above described, by the introduction of a simple temporary trussing to support the overhanging portion in rolling.

The lattice girders of the Cere Viaduct, Paris and Orleans Railway, spanning openings of 164 feet, were so rolled; as were also the plate girders of the Grand River bridge, Mauritius Railway.

The cost, per set, for erecting and fixing the girders in place, exclusive of the value of large tools, was Rs. 812 per set, divided thus:—

| | RS. | A. | P. |
|---|---|---|---|
| Unloading, setting up and rivetting, ... ... ... | 219 | 0 | 0 |
| Fixing rails, rolling and lowering, ... ... ... | 140 | 0 | 0 |
| Making and repairing all small tools, ... ... ... | 87 | 0 | 0 |
| Charcoal for rivetters and blacksmiths, ... ... | 62 | 0 | 0 |
| Superintendence, ... ... ... ... ... | 159 | 0 | 0 |
| Houses for men and miscellaneous, ... ... ... | 74 | 0 | 0 |
| Total, Rupees, ... | 812 | 0 | 0 |
| Or per opening, Rs. ... | 406 | 0 | 0 |

The cost of fixing rails, rolling and lowering, was about Rs. 17 an opening, for each opening rolled over. The value of materials used and depreciation of plant does not exceed Rs. 300 per set.

The masonry foundations, as well as all the iron work, were executed by the Madras Railway Company departmentally; while the well foundation

and fair work were done by Mr. E. W. Barnett, the contractor for the N. W. Line works.

The estimated cost of the Bridge was two lakhs and thirty thousand rupees, there being some 6,400 cubic yards of masonry in it. The contractor was paid Rs. 13 a yard for masonry; Rs. 2 for excavation; and Rs. 8 a lineal foot for wells, including concrete.

The Pennair bridge was only open for public traffic on the first of August last, though completed some months previously. The maximum deflection of the girders at the centre, with two engines coupled standing over and just covering one opening, was half an inch; and with the same two running 40 miles an hour, the deflection was $\frac{1}{32}$ to $\frac{1}{16}$ more, or a total of $\frac{9}{16}$th-inch.

With both spans uniformly loaded, the points of contrary flexure are each 48 feet from the abutment piers, and the points of maximum deflection 24 feet from the same.

When, however, one span only is loaded, (say with engines,) the point of flexure in the loaded span is about 54 feet from the abutment, and the point of maximum deflection is situated at about 27 feet from the face of the same abutment.

The calculations from which the above results are derived will be found in the Appendix.

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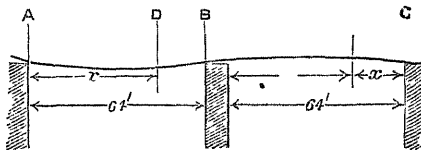
## APPENDIX.

### Calculations of Strains in the Girders.

Data from which the calculations have been made.

Dead load—Girders = 2·67 cwt. per foot run.
Rails, sleepers, &c., = ·83 " "
Permanent load = 3·50 " "

Greatest moving load = 10 cwt. per foot on each girder.

∴ Maximum load which can be brought on each girder = $13\frac{1}{2}$ cwt. per foot run.

First, to determine the points of flexure.

1*st.*—With a uniform load on both spans, $x$ the distance of the points of inflexion from the abutments, will $= \frac{3}{4}$th the span $= 48$ feet.

2*nd.*—With a maximum load on one span, the other unloaded, using the formula

$$x = \frac{7\,w - w'}{8\,w}\,l \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where

$x =$ Distance from the abutments in feet of the point of flexure.

$l =$ AB the clear span $= 64$ feet, or 768 inches.

$w =$ The load in cwt. per foot of AB $= 13\frac{1}{2}$ cwt.

$w' =$ ,, ,, BC $= 3\frac{1}{2}$ ,,

Substituting,—$x = \dfrac{7 \times 13\frac{1}{2} - 3\frac{1}{2}}{8 \times 13\frac{1}{2}} \times 64,$

Reducing,—$x = \dfrac{91 \times 64}{108} = \dfrac{5824}{108} = 53'\ 11''$, say 54 feet.

$$x' = \frac{7\,w' - w}{8\,w'}\,l,$$

Substituting,—$x' = \dfrac{7 \times 3\frac{1}{2} - 13\frac{1}{2}}{8 \times 3\frac{1}{2}} \times 64,$

Reducing,—$x' = \dfrac{704}{28} = 25'\ 1\frac{3}{4}''$, say 25 feet.

$\therefore\ x' = 25$ feet, the distance of the point of inflexion in the unloaded span from abutment.

Having determined the points of flexure, we can now find the maximum strains produced in the web and flanges of one span, by the maximum, or any other, load.

In order to determine these, we have to consider the span AB, as divided into two portions, AD and DB, the former AD, acting as an independent girder, supported by the abutment at A, and by the cantilever girder DB at D, and the latter DB, as a semi-girder, kept in place by BC.

1*st.*—The maximum flange strain in AD, will be given by the formula

$$W = \frac{8\,d\,f}{e}\left(a + \frac{a'}{b}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where

$W =$ Total load $= w\,l = 13\frac{1}{2} \times 54 = 729$ cwt.

$d =$ Depth between flanges $= 45$ inches.

$f =$ Strain per square inch or net section of either flange.

$l =$ Span $= 54$ feet $= 648$ inches.

$a =$ Net area of either flange $= 18$ inches.

$a' =$ ,, of web $= 17$ inches.

Substituting these values in (2).

$$W = \frac{8 \times 45 . f}{618} (18 + \frac{17}{6}); \text{ or, reducing}$$

$$729 = \frac{625 \times f}{54},$$

$$\therefore f = \frac{729 \times 54}{625} = \frac{39366}{625} = 63 \text{ cwt., nearly.}$$

Maximum flange unit strain $f = 63$ cwt. per square inch.

Total maximum strain on flange $= 18 \times 63 = 1,134$ cwt.

*2nd.*—The maximum strain on the web will be over the abutments, and $= \frac{W}{2} = \frac{729}{2} = 364$ cwt.

and the web unit strain $= \frac{364}{17} = 21\frac{1}{2}$ cwt.

The maximum strains in the cantilever DB, are produced by a single load at D, equal half the load on AD, or 364 cwt., and by the* uniform load over DB.

The strain due to the first is given by the formula

$$W = f \frac{d}{e} \left(a + \frac{a'}{b}\right) \text{ .......................... (3)}$$

It is to be remarked that the cantilever has a maximum length, and therefore sustains a maximum strain, when both spans of the continuous girder are covered by the maximum load, in which case DB $= 16$ feet as $x = 48$ feet.

$W = 48 \times 13\frac{1}{2} = 324$ cwt.

$d = 45$ inches.

$a = 23$ inches (as there is an extra plate).

$a' = 17$ inches.

$l = 16 \times 12 = 192$ inches.

Substituting these values

$$324 = \frac{f \times 45}{192} \left(\frac{23 + 17}{6}\right);$$

$$\therefore f = \frac{36 \times 192 \times 6}{155 \times 5} = \frac{216 \times 192}{775} = \frac{41472}{775} = 53\frac{1}{2}.$$

$f = 53\frac{1}{2}$ cwt. per square inch.

The strain produced by the uniform load is given by the formula

$$W = \frac{2 d f}{e} \left(a + \frac{a'}{b}\right) \text{ .............................. (4)}$$

$W = 16 \times 13\frac{1}{2} = 216$ cwt.

$l = 16 \times 12 = 192$ inches.

$a = 23$ square inches.

$a' = 17$ square inches, and $d = 45$ inches—Substituting in equation (4)

$$216 = \frac{2 \times 45 \times f}{192} \left(23 + \frac{17}{6}\right) = \frac{90 \times f \times 155}{192 \times 6}$$

Reducing, &c., $f = \frac{216 \times 192}{15 \times 155} = \frac{41472}{2325} = 18$, nearly.

$\therefore$ Total flange strain at B is $53\frac{1}{2} + 18 = 71\frac{1}{2}$.

$71\frac{1}{2}$ cwt. per square inch.

or, for the entire section, $71\frac{1}{2} \times 23 = 1644\frac{1}{2}$ cwt.

The maximum shearing strain in the web at B is

$$= W + wl, \qquad \text{......(5)}$$

$$\left.\begin{array}{l} W = 324 \text{ cwt.} \\ w\,l = 216 \quad \text{,,} \end{array}\right\} \therefore W + wl = 540 \text{ cwt.}$$

and the unit shearing strain $= \frac{540}{17} = 32$, nearly.

Having determined the maximum strains produced by the most unfavorable disposition of the maximum load, we may find the strain produced in rolling, given by the equation.

$$W = \frac{2\,d\,f}{e} \left(a + \frac{a'}{6}\right) \qquad \text{......(6).}$$

$W = 64 \times 2\frac{3}{4} = 176$ cwt.

$l = 64 \times 12 = 768$ inches.

$a = 23$ inches.

$a' = 17$ inches, and $d = 45$ inches—Substituting these in (6)

$$176 = \frac{2 \times 45 \times f}{768} \left(23 + \frac{17}{6}\right) = \frac{90 f}{768} \times \frac{155}{6}$$

$$\therefore f = \frac{176 \times 768}{15 \times 155} = \frac{135168}{2325} = 58 \text{ cwt.}$$

And the shearing strain on the web in rolling is $S = wl$;

or $S = 2\frac{3}{4} \times 64 = 176$ cwt.

or per unit $\frac{176}{17} = 10$ cwt., nearly.

In like manner, the strains produced by various dispositions of the load, may be calculated. The following table exhibits these strains, in the cantilever, and independent portion of the girder, under three dispositions of the load; and in rolling.

*1st.* Both spans unloaded, save by their own weight.

*2nd.* Both spans covered by the maximum load.

*3rd.* One span ,, ,,

*4th.* When a girder is being rolled on to a pier.

The deflections under the above loads, 1°, 2°, 3°, have been calculated from the formula. (*See* Table A.)

## A.

TABLE SHOWING the amount of the Strains produced in the Girders of the Pennair Bridge by the under-mentioned Loads.

| Mode of distributing load on each span of the continuous girder. | Strains in AD. | | | | Strains in DB. | | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | Tension and compression in flanges. | | Shearing in web. | | Tension and compression in flanges. | | Shearing in web. | | |
| | Per square inch. | On total section. | Per square inch. | On total section | Per square inch. | On total section. | Per square inch. | On total section | |
| | Cwt. | Cwt. | Cwt. | Cwt. | Cwt. | Cwt. | Cwt. | Cwt. | |
| Both spans unloaded, ... ... | 13 | 234 | 5 | 84 | 18 | 414 | 8 | 140 | |
| Ditto, covered by maximum load, ... | 50 | 900 | 19 | 324 | 71½ | 1644½ | 32 | 540 | Maximum strains in cantilever. |
| One span covered by maximum load, | 63 | 1134 | 21½ | 364 | 44 | 1012 | 29 | 499 | Maximum strains in AD. |
| Girder being rolled when in the position of greatest strain, ... ... | 58 | 1334 | 10 | 176 | ... | ... | ... | ... | |
| Maximum strains produced by the disposition of load which makes AD and DB of maximum length, ... | **63** | **1134** | **21½** | **364** | **71½** | **1644½** | **32** | **540** | |

$$D = \frac{5\, W\, l^3}{32 \,.\, E \,.\, (6\,a + a')\, d^2}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

in which

$D$ = Deflection in inches.

$W$ = Total load in lbs. on the girder whose deflection is required.

$l$ = Length in inches of " "

$E$ = Co-efficient of elasticity, 24,000,000 lbs. for wrought-iron.

$d$ = Depth of girder between flanges.

$a$ = Net area of either flange.

$a'$ = " " of web.

Substituting the proper values in each case and reducing by Logarithms, the following results are obtained. (*See* Table B.)

## B.

Table of Calculated Deflections of Pennair Girders.

| Distribution of load. | Maximum deflection. | | Remarks. |
|---|---|---|---|
| | Decimals of an inch. | Fractions of an inch. | |
| Both spans unloaded, ... | ·09 | $\frac{3}{32}$ | The maximum deflection is at 21 feet from the abutment. |
| Ditto with maximum load, ... ... ... | ·35 | $\frac{11}{32}$ | (same as above) |
| One span with maximum load, ... ... ... | ·57 | $\frac{9}{16}$ | Maximum deflection at 27 feet from the abutment. |
| Girder rolling, ... | 3·15 | $3\frac{1}{8}$ | Maximum deflection at end of girder. |

The deflection of the overhanging girder in rolling was calculated from this formula

$$D = \frac{3\, W\, l^3}{2\, E \,.\, (6\,a + a')\, d^2}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(8).$$

The above calculated deflections agree closely with those found by observation.

### TO FIND THE MAXIMUM DEFLECTION WHEN BOTH SPANS ARE UNLOADED.

$$D = \frac{5\, W l^3}{32\, E\, (6\, a + a')\, d^2}$$

$W$ = Total load in lbs. on the girder $= 48 \times 3\frac{1}{2} \times 112 = 18{,}816$ lbs.

$l$ = Length in inches of the girder $= 48 \times 12 = 576$ inches.

$E$ = Co-efficient of elasticity = 24,000,000 pounds.
$d$ = Depth of girder between flanges in inches = 45 inches.
$a$ = Net area of either flange in inches = 18 square inches.
$a'$ = „ of web in inches = 17 square inches.

| | | |
|---|---|---|
| Log. 5 = | ... ... ... ... ... ... | 0·6,989,700 |
| Log. W = log. 18816 = | ... ... ... ... | 4·2,745,273 |
| Log. $l^3$ = 3 log. 576 = 3 × 2·7604225, ... | ... | 8 2,812,675 |
| | Log of Numerator, ... | 13 2,547,648 |
| Log 3 = | ... ... ... ... ... ... | 1·5,051,500 |
| Log. E = log. 24,000,000, | ... ... ... ... | 7 3,802,112 |
| Log. $(6\,a + a')$ = log. 125, | ... ... ... | 2 0,969,100 |
| Log. $d^2$ = 2 log. 45 = 2 × 1 6532125, | ... ... | 3·3,064,250 |
| | Log. of Denominator, ... | 14 2,886,962 |

Log. D = 13·2,547,648 − 14 2,886,962 = $\bar{2}$·9,660,686

∴ D = ·092484 of an inch = $\frac{3}{32}$.

This maximum deflection is in the portion of the girder AD, and 24 feet from the abutment A, *i. e.*, at the centre of AD.

---

TO FIND THE MAXIMUM DEFLECTION WHEN BOTH SPANS CARRY THE MAXIMUM LOAD.

$$D = \frac{5\,W\,l^3}{32\,E\,(6\,a + a')\,d^2}.$$

$W$ = Load on girder in ℔s. = 48 × 13½ × 112 = 72,576 ℔s.
$l$ = Length in inches of the girder = 48 × 12 = 576 inches.
$E$ = Co-efficient of elasticity for wrought-iron = 24,000,000.
$a$ = Net area of either flange = 18 square inches.
$a'$ = „ of web = 17 square inches.
$d$ = Depth of girder between flanges in inches = 45 inches.

| | | |
|---|---|---|
| Log. 5 = | ... ... ... ... ... ... | 0·6,989,700 |
| Log. W = log. 72,576 = | ... ... ... ... | 4·8,607,930 |
| Log. $l^3$ = 3 log. 576 = 3 × 2·7604225 = ... | ... | 8·2,812,675 |
| | Log. of Numerator, ... | 13·8,410,305 |
| Log. 32 = | ... ... ... ... ... ... | 1·5,051,500 |
| Log. E = log. 24,000,000, | ... ... ... ... | 7·3,802,112 |
| Log. $(6\,a + a')$ = log. 125, ... | ... ... ... | 2 0,969,100 |
| Log. $d^2$ = 2 log. $d$ _ 2 × 1·6532125 = | ... ... | 3·3,064,250 |
| | Log. of Denominator, ... | 14·2,886,962 |

$$\text{Log. D} = 13{\cdot}8{,}410{,}305 - 14{\cdot}2{,}886{,}962 = \bar{1}{\cdot}5{,}523{,}343.$$

$$\therefore \text{D} = 0{\cdot}3{,}5672 \text{ inches} = \tfrac{11}{32} \text{ of an inch.}$$

The maximum deflection occurs at the centre of the segment AD, (which is, in this case, 48 feet long) or at 24 feet from the abutment.

---

TO FIND THE MAXIMUM DEFLECTION WHEN ONE SPAN CARRIES THE MAXIMUM LOAD, THE OTHER LIGHT.

$$D = \frac{5\,W\,l^3}{32\,E\,(6\,a + a')\,d^2}$$

W = Load on girder in lbs. $54 \times 13\frac{1}{2} \times 112 = 81{,}648$ lbs.

$l$ = Length in inches of the girder $54 \times 12 = 648$ inches.

E = Co-efficient of elasticity = 24,000,000.

$(6\,a + a') = 125$ inches.

$d$ = Depth of girder between flanges = 45 inches.

| | |
|---|---|
| Log. 5 = ... ... ... ... ... ... | 0·6,989,700 |
| Log. W = log. 81648, ... ... ... ... | 4·9,119,456 |
| Log. $l^3$ = 3 log. 648 = 3 × 2·8115750, ... ... | 8·4,347,250 |
| Log. of Numerator, ... | 14·0,456,406 |

As before Log. of Denominator = 14 2,886,962.

$$\text{Log. D} = 14{\cdot}0{,}456{,}406 - 14{\cdot}2{,}886{,}962 = \bar{1}{\cdot}7{,}569{,}444.$$

$$\therefore \text{D} = 0{\cdot}57140 = \tfrac{9}{16}, \text{ or } \tfrac{18}{32} \text{ inches.}$$

The maximum deflection occurs at a point 27 feet from the abutment A. AD = 54 feet.

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TO FIND THE MAXIMUM DEFLECTION IN ROLLING WHEN 70 FEET OVERHANGS.

$$D = \frac{3\,W\,l^3}{2\,E\,(6\,a + a')\,d^2}$$

W = Load on girder = $70 \times 2\frac{3}{4} \times 112 = 21{,}560$ lbs.

$l$ = Length in inches of the girders $70 \times 12 = 840$ inches.

E = Co-efficient of elasticity = 24,000,000.

$a$ = Net area of either flange = 18 inches.

$a'$ = ,, of web = 17 inches.

$d$ = Depth of girder between flange = 45 inches.

| | |
|---|---|
| Log. 3 = ... ... ... ... ... ... | 0·4,771,213 |
| Log. W = log. 21560 = ... ... ... ... | 4·3,336,488 |
| Log. $l^3$ = 3 log. 840 = 3 × 2·9242793 = ... | 8·7,728,379 |
| Log. of Numerator, ... | 13·5,836,080 |

| | |
|---|---|
| Log. 2 = ... ... ... ... ... ... | 0·3,010,300 |
| Log. E = log. 24,000,000 = ... ... ... | 7 3,802,112 |
| Log. $(6\ a + a')$ = log. 125 = ... ... ... | 2·0,969,100 |
| Log. $d^2$ = 2 log. 45 = 2 × 1·6532125 = ... ... | 3·3,064,250 |
| Log. of Denominator, ... | 13·0,845,762 |

Log. D = 13·5,836,080 − 13·0,845,762 = 0·4,990,318.

∴ D = 3·1552 inches = $3\frac{5}{32}$, or $3\frac{1}{8}$ inches.

The maximum deflection is at the overhanging end.

*7th December*, 1869. E. W. S.

# No. CCLXI.

## FLOOD DISCHARGE OF RIVERS.

*On the Relation of the Fresh-water Floods of Rivers to the Areas and Physical Features of their Basins; and on a Method of Classifying Rivers and Streams, with reference to the Magnitude of their Floods; proposed as a means of facilitating the investigation of the Laws of Drainage.* BY LIEUT.-COLONEL PETER PEIRCE LYONS O'CONNELL, R.E., Assoc. Inst. C.E.

*(Re-printed from the Proceedings of the Institution of Civil Engineers.)*

WHEN water falls in the shape of rain on any solid surface, whence it afterwards flows off, it forms its own drainage vehicle. It produces over that solid surface a certain depth of water with a certain superficial slope or fall towards an outlet; these two conditions, depth and surface slope, being necessary to produce flow. Should the solid surface be at all absorbent, the rain has also to furnish the quantity of water necessary to saturate it. While the drainage vehicle is forming and having its capacity increased, the water is flowing off the surface less rapidly than it falls upon it, and it is only when the time necessary for this preliminary operation of forming its own drainage vehicle has elapsed, that the water flows off from a surface as rapidly as it falls upon it. The time required increases with the linear distance between the upper and lower ends of the surface drained, and with the gentleness of its fall.

All natural surface drainage commences in the manner above described, which, for convenience of reference, will be termed "the first stage of natural surface drainage." It may then be said to be carried on and completed by rills, streams and rivers.

It will be evident from the above remarks respecting "the first stage

of natural surface drainage," that, should the rain cease before it has completed its own drainage vehicle, the rate of discharge from the surface upon which it falls will never equal the rate at which the rain has fallen upon it. This is also true of a drainage area or basin, consisting of many such surfaces discharging into natural streams or artificial drains. The larger the basin the greater the length of time for which rain must fall, in order that the rate of discharge by stream or river may equal the rate at which the rain falls. Hence it is that streams draining large areas are not subject to sudden floods caused by short smart showers.

An operation similar to that of rain forming its own vehicle of discharge, is performed by every river in its own channel, but this is especially the case with a river flowing through a lake. As long as the lake receives in a given time more water than it discharges, the river may be considered as increasing the capacity of its vehicle of discharge, inasmuch as it is raising the surface of the lake and increasing its rate of discharge. For want of time it does not complete its work. Hence the lake, like the extension of the area of a drainage basin, is a moderator of the flood discharge, resulting from a given rate of rain-fall. There are other natural moderators which are more or less effective; viz., a porous, absorbent soil, and the foliage of dense forests, but the latter has apparently the property, in some situations, of increasing the actual amount of rain-fall, which counterbalances its effect as a moderator of river floods. Snow may, according as it thaws slowly or rapidly, be a moderator or the reverse.

When a tributary in flood flows into a large main river, the channel of the latter acts very effectively as a moderator; the flood forming on the surface of the main river a wave, the summit of which is constantly being depressed as it travels down the river. The result of this depression is that the river discharges a smaller quantity per second at its mouth than at its junction with its tributary, if the latter is the only one in flood at the time.

Since mere extension of the area of a drainage basin is in itself a moderator, it is evident that if the rate of rain-fall diminished as its duration increased, the rate of discharge from a surface receiving rain would vary inversely as the distance between its highest and lowest levels; or, speaking generally, inversely with its area. Even if this be not absolutely correct, it may, for all practical purposes, be assumed to be true. And,

as an immediate deduction therefrom, it may be concluded that when rain falls upon steep, retentive, and clear ground, forming a drainage basin, the rate of discharge will approximate more closely to the maximum rate of rain-fall the smaller the area of that drainage basin, but that it can never exceed it. The maximum rate of rain-fall is thus shown to be a limit to which the rate of discharge approaches, under the favourable circumstances just mentioned, but which it never exceeds, except in extraordinary cases which will be alluded to hereafter, and which are here purposely excluded from consideration.

If a series of natural basins could be found increasing regularly in area, having physical features as to slope, soil, &c., all tending in the same degree to discharge the rain falling on them, and if the distribution of the rain were the same in all these basins, then doubtless the rate of discharge in floods might be represented graphically by some regular curve, the abscissæ of which would represent the area drained, and the ordinates the flood discharge per second. This curve would be concave to its base, and the tangent at its origin would have a value representing exactly the maximum rate of rain-fall. Such, however, are the diversities of physical features in river basins, and in the distribution of rain-fall in the world, that the search after the desired series of natural basins possessing exactly similar characteristics would probably be a vain one. This is to be regretted, for rivers small and great might alike be referred to some such curve, and classified as flood dischargers, according as they took up positions near to or distant from the curve.

To supply the place, as a classifier, of this unknown curve, the Author would suggest the use of the common parabola as follows :—Let $x$, the abscissa of a point in the curve, represent the area in square miles drained by a river ; and $y$, the ordinate of the same point, represent the number of cubic yards discharged per second by that river. Then in the common parabola $y = M . \sqrt{x}$ ; where M may be termed the modulus of the river, or of its drainage basin, as a flood producer. When M is large it will indicate that the physical features are such as to slope, soil, total amount and distribution of rain-fall, as to give the river and its drainage basin a high place in the classification. When M is small it will, on the contrary, indicate either that but little rain falls on the basin, or that it possesses some of those physical features which tend to moderate floods.

With the view of illustrating how far this method of classifying rivers

as flood producers is likely to prove useful, there are subjoined a few facts respecting the Mississippi and its tributaries, extracted from the report on that river prepared by Captain A. A. Humphreys and Lieut. H. L. Abbot, of the Corps of Topographical Engineers of the United States Army.

| Name of the river. | Area of its basin in square miles. | Rain-fall. | | Values of M. |
|---|---|---|---|---|
| | | Annual fall in inches. | Quantity drained off by the river in inches. | |
| Main Mississippi, | 1,244,000 | 30·4 | 7·6 | 49·28 |
| Ohio at Wheeling Bar, | 25,000 | .. | .. | 57· |
| Ohio at its mouth, | 214,000 | 41·5 | 9 96 | 56· |
| Red River, | 97,000 | 39· | 7 8 | 26·76 |
| Arkansas and White Rivers, | 189,000 | 29 3 | 4·395 | 13 06 |

It will be seen from this table, that while the number of inches of rain drained off annually by the Main Mississippi and by the Red River are 7·6 and 7·8 respectively, the values of M are 49·28 and 26·76 respectively. This difference is too great to be accounted for by the number of rainy days being greater in the basin of the Red River than in the basin of the Mississippi generally. If, therefore, the proposed method of classification be worthy of adoption, its evident indication of the existence of some flood moderator in the basin of the Red River, must be correct; and it will be found that it is so. There is in the Red River, according to the report just referred to, a remarkable raft, "composed of an immense accumulation of drift-logs—some floating, and others so water-logged as to sink, and thus still more effectively block up the channel. . . . . The obstruction of the raft has thrown a large proportion of the water of the river (about three-fourths) through two natural outlets (Dooley's and Red bayou) into Soda lake, affording a navigation around the raft (right bank), which is constantly improving as the action of the water widens and deepens these channels. . . . The range of the river is greatly affected by the raft. Thus at Fort Towson it is some 45 feet, the maximum (January 27, 1843) being 51 feet; at Fulton it is 35 feet; at the head of the raft, 10 feet; at Shreveport, 25 feet, at Alexandria, 47 feet; at the mouth, 45 feet. These numbers illustrate the effect of lakes in moderating floods. The raft also greatly modifies the normal succes-

sion of stages in the lower river, by equalizing the flow of the freshets, which are very sudden above the raft."

These extracts sufficiently prove, that the value of M for the Red River ought to have been, as it has been found, low; and tend to show that the proposed method of classification may be usefully, if cautiously applied. Nothing more can be claimed for it. It is to some extent empirical, and must be set aside whenever any other curve can be shown to suit the purpose better than the common parabola. In the meantime its application may be recommended, and its use will be hereafter further illustrated.

There are certain exceptional cases of river floods, which, not being regulated by the ordinary laws of drainage, must necessarily be excluded from a classification embracing only the usual results of physical causes. Several such cases are recorded by Sir Charles Lyell. The causes assigned for these are landslips or barriers of ice, closing for a time the outlets of valleys, accumulating large bodies of water, which ultimately burst their barriers, and escape within a few hours. It is also stated, that "a volcano in Lucanas (Peru) burst forth the same night (the 28th October, 1746), and such quantities of water descended from the cone that the whole country was overflowed; and in the mountain near Pataz, called Conversiones de Caxamarquilla, three other volcanos burst out, and frightful torrents of water swept down their sides." Inroads of the sea, caused by earthquakes, are of course excluded, as having nothing to do with fresh water floods.

Exceptional floods are also caused by the bursting of artificial reservoirs, by the destruction of bridges originally constructed without sufficient waterway, or of bridges constructed on streams at a period when, the regimen of their beds not being fixed, these were still being raised by accumulations of stones, gravel, or sand. In a case of the kind last mentioned, the waterway of the bridge, although ample at first for the passage of floods, becomes in time too small for the purpose. The bridge then forms an obstruction. It is at length swept away, and the waters, suddenly escaping produce unusual floods lower down the stream.

There are many small rivers in Southern India, where irrigation reservoirs or tanks are numerous, which were formerly, and to some extent are still, subject to excessive floods, caused by the simultaneous or successive bursting of a series of tanks situated in the same valley.

It is evident that, before any attempt at the classification of rivers or flood dischargers is made, all extraordinary floods similar to those mentioned must be excluded.

It is be regretted that data sufficiently extensive and accurate for the purpose of testing very rigidly any method of classification have not yet been collected. A compilation has, however, been made, from the Author's knowledge of Indian rivers, and from the statements contained in hydraulic works respecting European and North American rivers. These will be found exhibited in the table appended to this Paper (page 72), and in the diagrams attached to it (*Plates* VIII. and IX).

For the Indian rivers entered in this table the amximum values of M vary from 40 to 302·7. This may, at first sight, appear to be a very wide range; but the fact is, that if examples had been collected from every part of India, the range would have been from M = 0 to M = at least 2,000. The annual amount of rain-fall varies within the limits of Hindostan as much as in the whole world, for in parts of Scinde a shower is a rare occurrence. At Hyderabad the annual fall averages 3 inches, and at Kurrachee 8 inches; whereas at Chirrapoonjee, on the south face of the Cossya or Garrows mountains, 530 inches fell, according to Dr. G. Hooker, in six months of 1850, viz., from June to November, and of this 30 inches fell in twenty-four hours. There is nothing to show that these are excessive falls for the locality. The fall of 30 inches in twenty-four hours is probably below the maximum; for at Madras the fall has exceeded 17 inches in twenty-four hours twice within the last twenty years, whereas the annual fall has not exceeded 89 inches since 1813.

In the few examples given of North American rivers, the value of M varies from 13·06 to 57.

In the examples given of British rivers and streams the value of M varies from ·43 for a stream draining a small piece of meadow land to 37 for the Tyne. The maximum value of M would, it is supposed, be found in some stream in Cumberland or Westmoreland, before it falls into a lake, but it could hardly exceed 120. For by far the greatest portion of the country the value of M cannot exceed 15 or 20.

In the examples given of large European rivers, the values of M vary from 16 for the Seine, deduced from the discharge given by Dupuit, to 74 for the Danube at Pesth, which is somewhat uncertain, and probably too small. The value 67·53 for the Danube at its mouth is trustworthy,

being deduced from Sir Charles Hartley's Paper on the Danube. The value of M for the Loire at Pont de Fleurs, 20 miles above Roanne, is 196. The steepness of the hills east and west of the valley of the Upper Loire tend to give a higher value to M; but this is too high to be accounted for, except by the locality being also subject to heavy falls of rain, or sudden melting of snow.

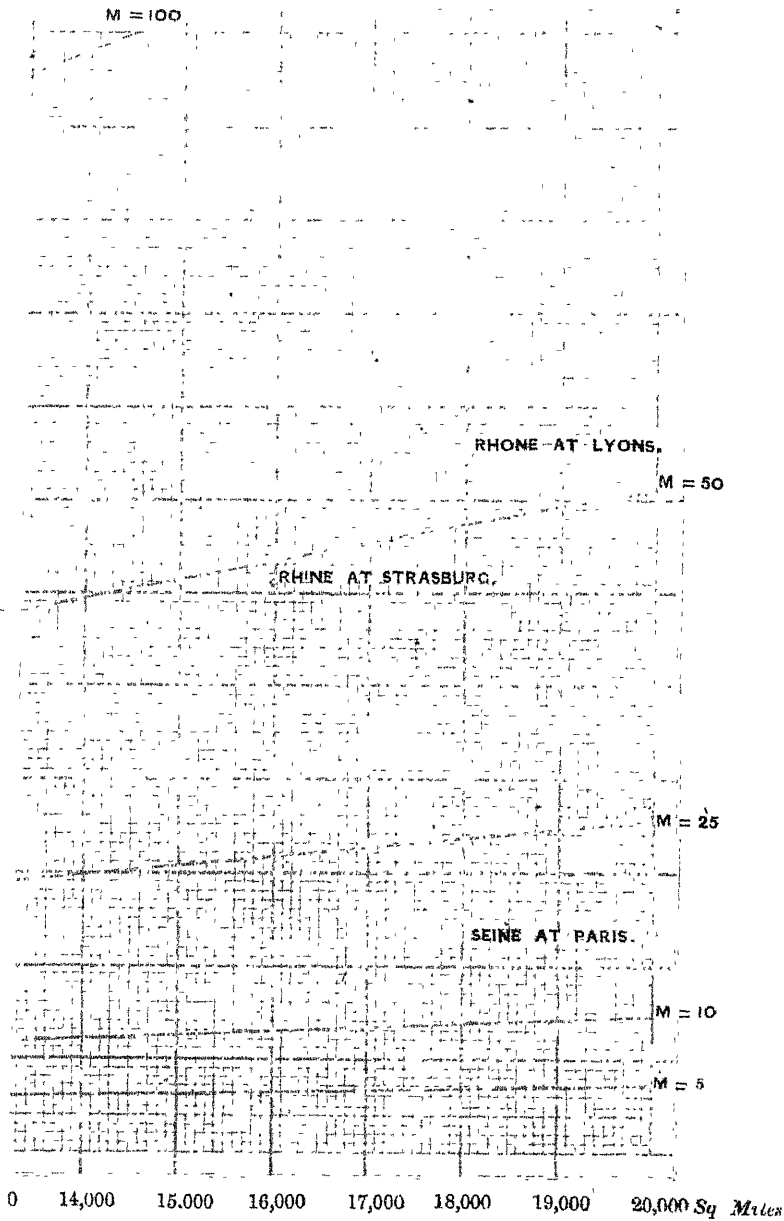
The value of M for the Nile, viz., 11·38, is remarkably low for a river rising so near the equator, showing, what is otherwise known to be true, that but little rain falls in that portion of the interior of Africa where the basin of the Nile is situated. This low value is also partly the result of the lakes and inundated country through which the river flows.

The value of M generally diminishes with the distance of a basin from the equator, just as the annual fall of rain diminishes, and the number of rainy days increases with distance from the equator. Both these rules are general, and liable to important exceptions, the causes of which are now partly understood, and are usually stated, as far as rain-fall is concerned, in works on Physical Geography.

These observations being general, and dealing with very wide differences in the value of M, may not at first appear to be of much practical use in an engineering point of view. This arises principally from the areas of country considered being very great. Each engineer may, however, ascertain for himself experimentally the value of M for the district in which he is employed; and, as a general rule, the smaller the district, the less will be the range in the values of M. It is important to observe, however, that whereas, in the case of large rivers, the parabola expressive of the relation between the area drained and the discharge per second may, without sensible error, be supposed to have its apex situated at the origin of the co-ordinates, in the case of small districts this supposition would lead to error. In the latter instance it becomes necessary to ascertain, at least approximately, what is the maximum rate at which rain falls in the district, and to place the origin of the co-ordinates at a point in the curve where the inclination of the tangent to the axis of $x$ shall correctly represent that maximum rate.

The late Major Jacob, when Astronomer in charge of the Madras Observatory, during an unusually heavy rain, measured the quantity which entered the gauge in ten minutes, and found that the fall had been at the rate of 5 inches an hour, or, in other words, that $\frac{5}{6}$ths of an inch

*PLATE VIII.*

M = 100
RHONE AT LYONS.
M = 50
RHINE AT STRASBURG.
M = 25
SEINE AT PARIS.
M = 10
M = 5
0
14,000
15,000
16,000
17,000
18,000
19,000
20,000 Sq Miles

had fallen in the ten minutes. According to Mr. Neville, it is stated that 4 inches of rain fell in one hour in the Holborn and Finsbury Sewers district.

For the sake of illustration, it will be assumed that a district exists in which the maximum rate of rain-fall is 5 inches an hour, and the maximum value of the modulus M is 20. This requires that the origin of the co-ordinates be situated at a point in the parabola where its geometrical tangent is inclined to the axis of $x$ at an angle whose trigonometrical tangent is 120. If $x'$ and $y'$ be the rectangular co-ordinates of the curve measured from this point, its equation is $y' = 20\sqrt{x' - \frac{y'}{120}}$; the areas being measured in square miles, and the discharges in cubic yards per second. But as, for small areas, it will be more convenient to measure the areas in acres, and the discharge in cubic feet per second, the formula becomes, when adapted to these new measurements,

$$y' = 21{\cdot}4\sqrt{x' - \frac{y'}{5}}$$

very nearly, or, after the solution of this quadratic equation,

$$y' = -\,45{\cdot}796 + \sqrt{2097{\cdot}28 + 457{\cdot}96\,x'}$$

The following table shows the discharge in cubic feet per second, from districts increasing in size from 10 acres to 5 square miles, computed by this formula. It illustrates the rapid diminution in the rate of discharge per acre, and in the proportion of the rain-fall represented by the rate of discharge as the area drained increases :—

| Area of district. | | Maximum discharge in cubic feet per second. | Maximum discharge in cubic feet per second per acre drained. | Representing rain-fall per hour in inches. |
|---|---|---|---|---|
| Square miles. | Acres. | | | |
| | 10 | 35·916 | 3·592 | 3·56 |
| | 50 | 112 303 | 2·808 | 2·78 |
| | 100 | 173 050 | 1·730 | 1·72 |
| | 200 | 260·291 | 1·301 | 1·29 |
| | 300 | 327·682 | 1·092 | 1·08 |
| | 400 | 384·647 | ·962 | ·95 |
| | 500 | 434·909 | ·870 | ·86 |
| 1 | 0 | 497·520 | ·777 | ·77 |
| 2 | 0 | 721·302 | ·564 | ·56 |
| 3 | 0 | 893·023 | ·465 | ·46 |
| 4 | 0 | 1037·934 | ·405 | ·40 |
| 5 | 0 | 1165 638 | ·364 | ·36 |

While the discharge from an area of 10 acres represents a rain-fall of 3·56 inches an hour, that from a district having an area of 5 square miles represents a rain-fall of only ·36 of an inch.

It is convenient to express the discharge in cubic yards per second, and the areas in square miles, for large districts, because a rain-fall of 1 inch per diem is represented approximately by a discharge at the rate of a cubic yard per second per square mile drained. In the case of small districts the discharge is more conveniently expressed in cubic feet per second, because a rain-fall of 1 inch per hour is represented approximately by a discharge of a cubic foot per second per acre drained. The error in the first case is rather less than $\frac{5}{12}$ths per cent.; in the second it is $\frac{10}{12}$ths per cent.

It will be seen, however, from the last table, that it is only in the case of very small districts that the rain-fall in so short time as one hour is correctly represented by the drainage discharge. The rates of flood discharge from a series of districts increasing in size would represent the mean fall of rain for several hours, days, and weeks; the rates of flood discharge from the largest districts representing the mean rate at which the rain fell for the longest periods. In the case of the St. Lawrence it is even stated, that the moderating influence of the great lakes is such, that the discharge of the river scarcely varies from its annual mean. If this be true, the rate at which the St. Lawrence discharges cannot even represent the mean rate of rain-fall per annum over its whole basin, for some loss of rain occurs from evaporation and absorption, and the remainder only finds its way by the river.

The following statement will show, however, that in rivers whose basins are by no means small, very extraordinary floods may occur in years not remarkable for large totals of rain-fall; the floods being produced in a cool season of the year, in a comparatively short time, by rain falling in quantities not large enough to raise the annual total above the average. The Seine, before passing Paris, has drained about 20,000 square miles of country. In a Paper in the "Annales des Ponts et Chaussées," it is stated that "in 1740, a year of formidable inundations throughout France, and, above all, at Paris, the annual mean fall of rain does not appear to have been much exceeded, but the first six months had been extraordinarily dry, and the two last extraordinarily rainy." In the year 1740 the Seine stood at 25 feet on the gauge at the Pont Royal of Paris,

and it has never risen to the same height since. This fact also shows the uncertainty of great floods, and the consequent necessity of applying a factor of safety to the experience of the oldest inhabitant of a town situated near a river, if it be really important that the highest floods be provided for in an engineering work.

In India the memory of the oldest inhabitant is often the only possible, though frequently a very uncertain source of information, respecting the heights to which a river in any neighbourhood has risen.

The factor of safety to be adopted cannot be determined beforehand, because information on the subject is still very imperfect. The adoption of the same factor for all parts of the world, or even of the same country, would in many cases lead to extravagant expenditure of money. There must, however, be for each river a factor, which applied to the average of, say ten years, in which the rain-fall is known to have exceeded the average of twenty-five successive years, would express without undue exaggeration the greatest probable flood of the next century. The examination of all existing records of river gauges and rain-fall would probably throw much light on the subject generally, and furnish hints in dealing with districts for which no records exist.

In conclusion a few statements and quotations will be given, as affording examples of flood moderators.

The effect of lakes is so well known as scarcely to need a reference. To this may be attributed the low value of the modulus M for the River Po, as compared with the Danube; the value for the first being only 37·9, while for the second it is as high as 74 at Pesth, and 67·53 at its mouth. Both these rivers drain the Alps, and the proportion of mountains receiving heavy falls of rain to the whole area of the basin is, if anything greater in the case of the Po than in that of the Danube. The mean fall of rain per annum, as given by Mr. Keith Johnston, is 57·57 inches for the south face of the Alps, and only 35·27 inches for the north face; so that, if there were no lakes in the basin of the Po, its modulus would most probably have been more than double what it is at present.

The River Thames furnishes a striking example of floods being moderated by the geological structure of a drainage basin. A very large proportion of this basin consists of chalk. Mr. S. C. Homersham, M. Inst. C.E., has contrasted the waterway and the drainage grounds of nine pairs of bridges—one bridge of each pair crossing a stream draining an area

of chalk, and the other crossing a stream draining a nearly equal area of the London clay, or of London clay with a little chalk. The ratios of the waterways of the bridges crossing streams draining chalk to the waterways of the bridges crossing streams draining clay varies nearly from $\frac{1}{10}$th to $\frac{3}{10}$ths, and while the former were never full of water, and sometimes never two-thirds filled with water, the latter were often filled with flood water. The velocities of the streams are not given. It is not, therefore, possible to make the comparison accurately, but enough is stated to show the decided effect of chalk in moderating floods, and to account for the low value of (M) the modulus for the Thames, viz., 5·24.

The beds of most rivers of Southern India are dry for many months in the year. Some of these beds appear to be connected with extensive strata of sand near the sea, so that the first floods of the wet season are very much moderated, and in some instances lost before reaching the sea. The Pennair, a river entering the sea near the town of Cuddalore, has a total length of 250 miles. It drains about 6,000 square miles of country. The water was 3 feet deep in this river at Munnaloorpett on the 16th of May, and again 6 feet deep on the 4th of June, 1855, at Riandaveray, while at Cuddalore there was no sign of a fresh, the whole having been absorbed in the 60 miles of river bed lying between the two last places mentioned.

The moderating influence of the channel of a main river upon floods delivered into it by its tributaries is exemplified on a magnificent scale in the river Mississippi, as the following extract from the Report on the Mississippi by Captain Humphreys and Lieutenant Abbot clearly shows:

"The rise in December, 1857, admirably illustrates this influence, since the water was then entirely confined to the channel, and the effect of crevasses is thus eliminated from the problem. This rise was at its height (8·5 feet below high water of 1858) at Columbus on December 21, the maximum discharge being 1,190,000 cubic feet per second. The St. Francis river was backed up, and contributed nothing. At Napoleon, the rise attained its highest point (7·1 feet below high water of 1858) on December 28. On December 29, the measured discharge of Arkansas river was 65,000 cubic feet per second. On January 1, the river had fallen 2·2 feet at Napoleon, and the measured discharge of Arkansas river was 59,000, and of White river 48,000 cubic feet per second. It is evident, then, that these two rivers must have added at least 100,000 cubic feet per second to the top of the flood wave, as it passed. At Yazoo river, according to accurate data, it received 45,000 cubic feet per second more. At the top of the flood at Natchez, which was 8·3 feet below high water, 1858, the discharge then should have been 1,190,000 + 100,000 + 45,000 = 1,335,000 cubic feet per second. It was measured on January 8, when the river had fallen 1·6

foot, and was found to be 845,000 cubic feet per second. Allowing a very liberal estimate for diminution of discharge at this date, the rise when highest could not have carried past Natchez more than 935,000 cubic feet second. How, then, is this enormous difference of 400,000 cubic feet per second to be accounted for? Only in one way. The reservoir furnished by 550 square miles of channel betwen Columbus and Natchez absorbed it all. This is an extreme case, because such a rise at so low a stage is almost unprecedented, but it plainly shows that so important an element cannot be neglected in discussing the subject of river floods."

Sometimes one of the tributaries of a river, instead of increasing its flood, moderates it by receiving water at the height of the flood, and returning it to the main river when that is falling. M. Dupuit states that the Maine relieved the Loire for three days when the flood of 1846 was at its height at the rate of 1,000 cubic mètres per second. So that the Loire below the mouth of the Maine was discharging 1,000 cubic mètres per second less than above the mouth of that river.

P. P. L. C.

TABLE EXHIBITING A FEW OF THE PHYSI

| Continent and country to which the river belongs. | Name of the river. | Area of its basin in English square miles. | Flood discharge of the river in cubic yards per second. |
| --- | --- | --- | --- |
| *North America.* | | | |
| United States. | The Mississippi, . . . | 1,244,000 | 55,000 |
| | Ohio at Wheeling Bar, . | 25,000 | 9,000 |
| | Ohio at its mouth, . . | 214,000 | 26,000 |
| | Red River, . . . . | 97,000 | 8,333 |
| | Arkansas & White Rivers, | 189,000 | 5,930 |
| | Yazoo River, . . . . | 13,850 | 5,160 |
| *Europe.* | | | |
| England. . . | Thames, . . . . . . | 5,000 | 293<br>370 |
| | Severn, . . . . . . | 3,890 | 464 |
| | Tyne, . . . . . . . | 1,100 | 1,233 |
| | Nene at Higham Ferrars, | 383 | 79 |
| | Meadow Land, . . . | ·128 | ·1536 |
| Scotland. . . | Tay, . . . . . . . | 2,283 | 465 |
| | Clyde, . . . . . . . | 945 | 120 |
| | Conon, . . . . . | 399 | 133 |
| | Earn, . . . . . . . | 340 | 132 |
| Ireland. . . | Shannon at Killaloe, . . | 4,687·5 | 617 |
| | Lower Erne at Belleek, . | 1,521·9 | 404 |
| | Upper Erne at Belturbet, | 482·8 | 159 |
| | Woodford at Ballyconnell, | 140·6 | 62·2 |
| | Yellow River, . . . . | 7·8 | 32·1 |
| | River Robe at Ballinrobe, | 110 | 71 |
| France. . . | Seine at Paris, . . . | 20,000 | 2,350 |
| | Rhone at Lyons, . . . | 18,000 | 7,500 |
| | Rhine at Strasbourg, . | 16,000 | 6,100 |
| | Loire at Pont de Fleurs, 20 miles above Roanne, | 2,200 | 9,200 |
| | Lot, a tributary of the Garonne, . . . | 6,000 | 2,770<br>2,783<br>2,790<br>3,400<br>4,320 |
| Italy. . . . | Po at Ponte logoscuro, . | 40,000 | 7,580<br>6,760 |
| | Reno, . . . . . . | 417 | 435 |
| Central Europe. | Danube at its mouth, . | 300,000 | 12,000<br>37,000 |
| | Danube at Pesth, . . | 72,850 | 20,000 |
| *Africa.* | Nile, . . . . . . | 1,400,000 ? | 13,400<br>12,000 |
| *Asia.* India, . . . | Ganges at Rajmahal, . | 345,000 | 50,000 |
| | Godavery at Rajahmundry | 120,000 | 50,000 |
| | Kistnah at Beizwarah, . | 110,000 | 44,000 |
| | Toombuddra at Kurnool, | 20,000 | 10,000<br>22,000 |
| | Cauvery at Seringham, . | 28,000 | 17,500 |
| | Ditto at Fraserpett, . . | 415 | 3,600 |

| Flood discharge of the river in cubic yards per second, per square mile drained. | Values of M. | Authorities for the Statements recorded in column 4, with some additional information. | | |
|---|---|---|---|---|
| | | Mean rain-fall per annum. | Ratio between drainage and downfall. | |
| ·044 | 49·28 | 30 4 | ·25 | Captain Humphreys and Lieut. Abbot's Report. |
| ·36 | 57· | | | |
| ·122 | 56· | 41·5 | ·24 | |
| ·086 | 26·76 | 39· | ·20 | |
| ·0313 | 13·06 | 29·3 | ·15 | |
| ·372 | 44·1 | 46 3 | ·90 | |
| ·0586 | 4·15 | Encycl. Britannica. Article, 'Inland Navigation.' | | |
| ·074 | 5·24 | Ditto ditto ditto. | | |
| ·119 | 7·4 | Beardmore's Hydraulic Tables, page xxvii. | | |
| 1·12 | 37· | Ditto ditto | | |
| ·207 | 4·03 | Ditto ditto | | |
| 1·2 | ·43 | Ditto ditto page xxviii. | | |
| ·203 | 9·75 | Encycl. Britannica. Article, 'Inland Navigation.' | | |
| ·127 | 3·9 | Ditto ditto ditto | | |
| ·333 | 6·7 | Ditto ditto ditto | | |
| ·39 | 7·2 | Ditto ditto ditto | | |
| ·132 | 9·01 | Neville's Hydraulics, 2nd edition, page 298. | | |
| ·265 | 10·04 | Ditto ditto | | |
| ·329 | 7·4 | Ditto ditto | | |
| ·442 | 5·24 | Ditto ditto | | |
| 4·12 | 11·46 | Ditto ditto | | |
| ·645 | 6·8 | Ditto ditto, page 302. | | |



| | | |
|---|---|---|
| ·116 | 16 | Dupuit, 'Etudes Théoriques et Pratiques sur le mouvement des Eaux,' page 191. |
| ·416 | 56 | D'Aubuisson's Hydraulics. English Translation by Bennett, page 174. |
| ·381 | 48 | Ditto ditto ditto |
| 4·18 | 196 | Flood of October, 1846. *Vide* Beardmore's Hydrology, page 161. |
| ·461 | 35·7 | 7th January, 1860 — 'Annales des Ponts et Chaussées.' Mars et Avril, 1865, page 154. |
| ·464 | 35 85 | 1st June, 1856 |
| ·465 | 36 | 26th January, 1856 |
| ·566 | 43·9 | 5th February, 1833 |
| ·720 | 55·3 | 1783; tradition. |
| ·1895 | 37·9 | Buffon, 'Traité des Irrigations,' vol. ii., page 31 |
| ·169 | 33 8 | Courtois, 'Traité des Moteurs,' page 316. |
| 1·04 | 21·32 | Buffon, 'Traité des Irrigations,' vol. ii., page 31. |
| ·04 | 22· | Ordinary fresh — Sir Charles Hartley. *Vide* Minutes of Proceedings Inst. C E. vol. xxi., pp. 278 and 281 |
| ·1234 | 67 53 | High fresh |
| ·272 | 74· | High fresh. Rough and uncertain computation from data in the Supplement to the work on Bridges, published by Weale. |
| ·00957 | 11·38 | Encyclopædia Britannica, vol. xvii., page 608. |
| ·00857 | 10 17 | Captain Fyfe, R. E, in a Report to the Bombay Government. |
| ·145 | 85 | Major Lang, Superintendent of the Nuddea River, in No. XIX. of the 'Selections from the Records of the Government of Bengal.' |
| ·416 | 144·3 | |
| ·4 | 133 | |
| ·5 | 70 2 | Captain (now Colonel) Lawford, R.E. |
| 1·1 | 155 5 | Captain Beckley, R.E. Probably too high an estimate. |
| ·625 | 104· | |
| 8·7 | 177· | |

TABLE EXHIBITING A FEW OF THE PHYSICAL FEATURES OF CERTAIN RIVERS—*Continued.*

| Continent and country to which the river belongs. | Name of the river. | Area of its basin in English square miles. | Flood discharge of the river in cubic yards per second. | Flood discharge of the river in cubic yards per second, per square mile drained. | Values of M. | Authorities for the Statements recorded in Column 4, with some additional information. |
|---|---|---|---|---|---|---|
| *Asia.* India, . . . | Pennair at Nellore, . . | 20,000 | 13,300 | ·67 | 94·4 | |
| | Palaur at Arcot, . . . | 3,700 | 4,160 | 1·12 | 68·8 | Colonel Collyer, R.E. |
| | | | 10,000 | 2·7 | 164·39 | Tradition. |
| | Tambrapoorny at Palamcottah, . . . | 587 | 2,000 | 3·4 | 82·37 | Ordinary fresh. |
| | | | 7,000 | 12· | 289· | Inundation, described in the Government Records of the Tinnevelly district. |
| | Chittaur at Allighyapandiyapooram, . | 486 | 200 | ·41 | 9·07 | Ordinary fresh. |
| | | | 1,100 | 2·26 | 49·9 | Extraordinary fresh. |
| | Vigay at Madura, . . | 1,600 | 800 | ·5 | 20· | Ordinary fresh. |
| | | | 1,600 | 1· | 40· | Extraordinary fresh. |
| | Munjelnaltree at Ballagoontoo, . . . | 90 | 400 | 4·44 | 42 16 | Ditto ditto. |
| | Varhaganaltree at Periacolum, . . . . | 41 | 300 | 7·3 | 46·8 | Ditto ditto. |
| | Irrity in Malabar, . . | 336 | 3,700 | 11· | 201·8 | General Ludlow, R.E. |
| | | | 5,550 | 16·5 | 302·7 | |
| | Sohan River, Lahore and Peshawur Road, . | 573 | 3,370 | 5·9 | 141· | 'Indian Engineering,' vol. i., page 177. |

# No. CCLXII.

## SLUICES OF THE MAHANUDDY ANICUT.

*An account of experiments made with the French pattern Sluices of the Mahanuddy Anicut.* BY J. P. H. WALKER, ESQ., *Supdg. Engineer, Orissa Irrigation Circle.*

THE centre sluices are divided into ten bays of 50 feet each by piers of masonry. Each bay is closed by a double row of timber shutters, which are fastened by wrought-iron bolts and hinges to a heavy beam of timber embedded in the masonry floor of the sluices. There are seven upper shutters and seven lower or rear shutters. The latter are 9 feet in height above the floor, and the former $7\frac{1}{2}$ feet.

During floods, therefore, the upper row of shutters which fall forward is fastened down by clutch gearing in an almost horizontal position, while the rear set of shutters which fall backward is kept during flood in a horizontal position by the water-rushing over.

During the summer season, these rear shutters have to do the duty of damming up the water, and for this purpose they are provided with strong wrought-iron stays or struts attached to them behind, or on their lower side. As it would be almost impossible, however, to lift these back shutters with a depth of $5\frac{3}{4}$ feet of water tearing over them, the upper shutters are so constructed as to render this a matter of comparative ease. As the upper shutters point up-stream, the natural tendency of the powerful current passing over is to lift them up. By simply unclutching them, therefore, they immediately rise and dam up the water, being retained in position by two sets of chains, which take the strain off the hinges. The water being thus dammed up, the back shutters are easily lifted, and

permit in their turn of the upper shutters being lowered forward into their horizontal position.

When the experiments commenced this morning, the pressure on the rear shutters was $5\frac{1}{4}$ feet. From the time that Mr. MacMillan, who conducted all the operations, commenced to unship the back stays of the rear shutters, to the complete re-damming of the water by the rising of the upper shutters, only $7\frac{1}{2}$ minutes elapsed. Three men, wielding a wooden beam, knocked in succession the free end of each iron stay out of the cast-iron recess or shoe which retained it in position on the floor. The stays belonging to the last shutter were unshipped by a lever from the top of the first pier. When done with care, this operation of lowering the back shutters is attended with no undue risk. When the second last shutter fell, the men stood in perfect security behind the last one of all, although the current was swirling round the edge of it with a velocity that nothing could withstand. The velocity, as measured near the wall by the current-metre, was 8·60 feet per second, but in the thread of the current it was probably 10 feet per second. Two boats were ready at the rear of the apron in case any of the men should be carried away. There is also the danger, of course, of the back stays slipping and coming down on the men, but this can only arise through carelessness.

The re-damming of the water was accomplished in less than a minute. By reversing a lever, each of the upper shutters became released; they did not rise successively, but according as the current acted more or less strongly under each shutter. Each shutter rose to the water surface with a comparatively slow motion, but from the water surface it came home with a sharp jerk, bringing no greater strain, however, than they seemed quite able to bear.

The next operation was to lift the rear shutters, which had been lowered, and this was accomplished, for the seven shutters in the bay, by twelve men in exactly ten minutes. All they had to do was to re-place the free end of the wrought-iron back stays in the recesses referred to above, and the shutters were secured. When the angle irons fitted between, each shutter was pushed into place, the space between the upper and lower shutters gradually filled with water, and each of the upper shutters being thus relieved of the strain, could no longer remain in the vertical position, but quietly fell forward by its own weight until it attained an angle of 45°, when it remained in a state of flotation.

To get the upper shutters sufficiently lowered so as to be clutched by the moving back of the lever, it was necessary to place two men in each shutter so as to weight it down. A boat was also brought alongside to assist them in doing this. The re-placing of the seven upper shutters into their horizontal position took from 18 to 25 minutes. This is a part of the process in which a few minutes one way or other makes no difference.

The experiment of opening and lowering the first bay of the sluices in the manner above described was performed a second time with similar results, which must be considered satisfactory. The lowering of the whole 500 feet of the sluices, by even the means at present at our command, will only take one hour; while, at the end of the season, the damming of the water by the upper shutters need only be the work of 25 minutes. From the facility with which the shutters were manœuvred, and the absence of any excessive jerking of the chains or concussion of the falling shutters,* I hope for the best results. I shall be anxious throughout the freshes, however, about the action of the two bays of the upper shutters, which are fitted with the hanging clutch, as this is undoubtedly an imperfect arrangement compared with the under clutch attached to the disengaging bars. With the exception of the northmost bay, the back shutters have as yet no disengaging gear. They have to be lowered, as I have shown, by men going behind and knocking away the struts. The want of this disengaging gear will cause no trouble.

It is with satisfaction that I find myself able to report these sluices in working order before the rains, and as I consider that much is due to Mr. Barnes of the Jobra Workshop, who worked late and early to bring the timber and iron-work forward, so that everything might be fitted in place before the rains; I hope that his services may not be forgotten. It would have been a most serious disappointment, as well as a source of great trouble and expense, had the unfinished state of the sluices necessitated the re-construction of the dam after the rains.

*P.S.*—Since writing the above, all the shutters in seven other bays have been experimented upon with equally satisfactory results. The disengaging gear, by which the struts or back stays which support the rear shutters are thrown down, answered its purpose very well. From these experiments, we have drawn the following conclusions:—

* So completely did the rush of water under and around the falling shutters break their fall, that even the paint on the brackets which fasten the back stays to the shutters was not rubbed off.

*1st.*—That with the shutters constructed on the French pattern, and with a head or pressure of between 5 and 6 feet, 500 lineal feet of shutters can be easily lowered in one hour.

*2nd.*—That, under the same condition, an equal length of opening can be closed in 25 minutes. In closing, the shutters may be said to be self-acting.

*3rd.*—That when the back stays are released, the falling shutters are received upon a cushion of water in time to prevent any undue concussion.

*4th.*—That the action of the water in lifting the upper shutters brings no excessive jerk on the chains; but that it is advisable that chains have an adjusting screw fitted on, so as to make the strain perfectly uniform. The shutters were brought home in a current of 10 feet per second.

*5th.*—That three men can knock away the back stays with a pressure of between 5 and 6 feet with ease and security.

*6th.*—That twelve men are necessary to lift each of the back shutters into position.

CUTTACK,
*June 20th*, 1869.

J. P. H. W.

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# No. CCLXIII.

## THE JUMNA BRIDGE—DELHI RAILWAY.

By Imrie Bell, Esq. M.I.C.E.

[*Re-printed from the Proceedings of the Institution of Civil Engineers.*]

The bridge, the foundations of which form the more immediate subject of this Paper, is on the Delhi railway, and crosses the river Jumna about 37 miles south-east from Umballa, near a village called Sirsawa. The banks at the crossing are well defined, but will require protecting groynes, so as to keep the water in its proper channel, as, like other Indian rivers with banks composed of a sandy soil, it is constantly changing its course.

The Jumna takes its rise in the Himalayas, and debouches into the plains at a place called Hatni Koond, where the canal heads are formed for diverting the water into the Eastern and Western Jumna canals. The bed of the river at this place consists of large boulders, from 14 lbs. weight and upwards; this continues to within about 6 miles above the bridge, when it gradually changes to gravel and coarse sharp sand.

From borings, and also from the stuff excavated from the wells, it was found that during the floods, when the velocity of the river reaches 8 miles an hour, as it did in the rainy season of 1867, the large boulders are brought down as far as the site of the bridge, and are deposited by the scour of the current as deep as 30 feet below the level of the bed of the river in the dry season. As the level of the water falls at the end of the rainy season, the stones decrease in size, till the bed changes to

coarse and fine gravel and coarse and fine sand, and over this a deposit of very fine sand and silt. The section is as follows:—

2 feet alluvial soil.
18 feet fine sand, in some places mixed with earth, clay, and kunkur.
5 feet coarse sharp sand, fit for building purposes.
5 feet coarse sharp sand, with gravel.
12 feet coarse sand and gravel, interspersed with layers of blue clay, from 6 inches to 2 feet thick.
5 feet coarse gravel, and boulders of limestone and quartz.
2 feet large boulders up to 15 lbs. weight.
4 feet coarse gravel, sand, boulders, with layers of stiff blue and yellow clay.
—
53 feet.

In each pier of this bridge there was a group of ten wells, two rows of four in each row, with one on the up and another on the down-stream side for cut-waters. From the Author's experience in well sinking, he is of opinion that it would be preferable to have only one row, as there is continual trouble in some of the wells in either line getting off the plumb, and becoming jammed either against the top or the bottom of the ones opposite. Very often in removing the stuff from under one side of the curb, to bring it back to the perpendicular, the opposite well would lean over, from the stuff running from under its curb at the same part. In order to avoid this, and to insure speedier sinking, a plan might be adopted of having only one row of wells in the breadth of the pier, which would generally not necessitate a larger well than 18 feet in diameter, the sinking of which could be easily managed.

The well-sinking was proceeded with continuously, there being day and night shifts of labourers, ten men and a mate, or overseer, for each well, and the average rate of sinking was—

| | | |
|---|---|---|
| For the first ten feet | = | five feet per week. |
| From ten to twenty feet | = | three feet per week. |
| From twenty to thirty feet | = | two feet per week. |
| From thirty to forty feet | = | one foot two inches per week. |
| From forty feet | = | six to four inches per week. |

The labour was paid by a system of task-work at the following rates:— For the first five feet, ten shillings; and for every additional foot up to ten feet, ten shillings more; and so on, fifty shillings for every additional five feet. As a rule, this satisfied the men and paid them very fairly; but occasionally, where hard strata were met with, an addition to the rate had to be made, or the divers with Siebe's diving dresses had to go down

and excavate the stuff, and let the well sink through the bed of kunkur or other hard material, and then the taskwork was recommenced.

There are twenty-four openings, each having a waterway of 99 feet in the clear. The total length between the abutments is 2,663 feet 6 inches, thus leaving a waterway of 2,376 feet. The superstructure consists of two lines of lattice girders, resting on single brick columns, each 12 feet 6 inches external diameter. The rails are 29 feet 6 inches above low-water level, and are fixed to longitudinal timbers, which are bolted down upon the girders. There is a footpath on each side supported upon cantilevers projecting from and riveted to the girders, and protected by a light wrought-iron railing.

The working season at this bridge was during the months between October and June, for operations in the bed of the river, brick-making, and lime-burning; but the work in the shops could be carried on during the whole year, except when there were extraordinary floods, as in 1867, when the river rose 2 feet higher than the banks and inundated the country for nearly 2 miles on either side. The river showed a strong tendency to scour away the east bank; and the plan first adopted for its protection, was to throw out a series of spurs at the places where the river seemed inclined to flow towards the centre of the channel. This was done by driving two lines of piles, and filling the space between with bags of the firmest material that could be procured near the sites of the spurs; and the down-stream side was filled up to the level of the bank with earth and sand. But during the following rainy season, the river rose 14 inches higher than the highest floods recorded by the engineers in their preliminary surveys and sections, scoured away the spurs, and cut into the bank about 150 feet.

The Author subsequently received instructions to adopt measures for the permanent conservation of the bank, as it was thought the river might burst through the embankment at the back of the abutment of the bridge. On consideration, it was decided to erect a spur or groyne that would tend to divert the scouring force of the river, without seriously impeding the flow of the water. This consisted of three rows of piles of sál timber, placed at about an angle of 45° to the line of the stream. The first row was driven to a depth of 20 feet below the bed of the river, and the top of piles was cut off at the level of the bed. The second row, about 3 feet behind, was driven about 15 feet below the bed, and the tops of piles

were left about 2 feet above the highest recorded flood; the third or back row, about 5 feet behind, was driven in a similar manner to the second row, and left at the same level, the whole being well tied and braced with walings and diagonals, firmly secured with bolts and nuts. The front face on the up-stream side was sloped from the level of the ordinary bed of the river up to the head of the second row of piles, and the surface was planked over with 2-inch boards, spiked to the diagonals at intervals of 2 inches. The entire space between the front and the back rows of piles was filled in with fascines, (made of coarse wicker work,) and stones, sand-bags, and branch wood, so that the water flowed freely through the spur without any violent rush to hurt the bank. This description of spur acted successfully, and although tried severely in 1867 by the strong flood, only one of the three spurs was seriously damaged. These spurs not only protected the bank, but induced sand and silt to deposit at the back, and the bank of the river was brought out about 60 feet beyond the line it occupied before the spurs were erected.

In diverting the river at different points during the dry season, in order to get the sites of the piers clear of water, it was found to be more quickly and economically accomplished by gentle means, tending to catch the particles of sand held in suspension by the water, than by the rougher mode of forming earthen bunds or dams. The plan generally adopted was to drive a line of piles, or bullees, of saplings, 15 feet to 18 feet long and 6 inches in diameter at the butt, and to bind them firmly with moonj ropes (a species of hemp); then a large fascine, made of long grass, twisted together and bound, was let down in the front of the piles, and held in position by sand-bags. It was curious to notice the effect of this day by day. The depth of the water decreased on the down-stream side of the piles: and at the end of two or three weeks, the river was entirely diverted into the other channel, which had been deepened, and slightly widened, in order to assist the operation. Where this plan could not be carried out, owing to too great depth of water, islands were formed for each pier, by driving piles on the up-stream side, and binding them together at the water level with moonj rope. These piles were driven in the form of half a circle, and sand-bags were lowered on the down-stream side to the height of 4 feet or 5 feet; and then sand was filled in by coolies with baskets to the height of 5 feet above low-water.

This height had to be maintained, in case of a sudden rise in the river by one or both of the canals being shut off for repairs, when the water would rise 4 feet. This happened several times, and was most annoying. The engineers in charge of the canal works could not, in many instances, give the Author notice before closing the sluices, as it was generally on account of some accident to the foundations of bridges, or canal banks, and had to be attended to without delay. The melting of the snows on the Himalayas in the month of April, sometimes sooner, and at others later, according to the season, had likewise to be guarded against, as at that time the river would rise 3 feet to 4 feet in as many hours. This only lasted three or four weeks, but it had to be watched, as it could not be foreseen where the scour might occur.

On the completion of the islands, sleepers were laid down, and the segments of the wrought-iron curb, on which rests the brickwork forming the steining of the well, were placed in position and riveted together. *Plate* XI., *Fig.* 1, represents one of the curbs, showing that in cross section it is like an inverted right-angle triangle, the height of which is 4 feet and the base 3 feet 7 inches. The outer edge of this curb is 12 feet 6 inches, and the inner edge 5 feet 4 inches, in diameter. These curbs were made in England, were sent out in segments, and were put together in the following manner:—

The gusset plates A, twelve in number, framed with angle irons E were fixed in position, and temporarily bolted to the outside circular plates, from which they radiated inwards, forming in cross section a V shape; the top of the V being the top segmental plates C, which were placed upon the gusset frames, and fixed with bolts and drifts to the angle iron ring H, the whole being riveted together. Finally the inside sloping plates D were fixed and riveted to the angle irons E, which finished the operation. The sleepers were then taken away, and the entire curb moved into position in the centre of the pier, when the compartments between the gusset plates A were filled with concrete, composed as follows:—

1 part clean sharp sand.
3 parts broken brick or stone.
1 part fresh burnt lime.

The curb was sunk by men with the phoura and basket, till the upper plate was within 3 inches or 4 inches of the level of the water, when six upright bolts K (two of which are shown in section) were fixed, and the

brickwork of the cylinder or well was commenced. The steining or wall of the well was 3 feet 4 inches thick, and the inside diameter was 5 feet 10 inches. When the building had been carried up 6 feet, the well was sunk by means of the jham and divers in the old native style, then 10 feet additional were built, and sunk by the Sand-Pump (to be hereafter described) worked by a steam hoist of 4 H.P.; then another length of 15 feet was built, and sunk in the same manner, after which the final 15 feet were built, and sunk, which carried the well down to its full depth.

Well sinking, or cylinder sinking, is an extremely simple and easy operation, if care and attention are given to it. The Author has found from an experience extending over nearly nine years in India upon bridge works, that the main point to be attended to is to get the well fair and straight for the first 10 feet, and there is not much to fear after that. To insure this, the curb should invariably be sunk alone, without any building, and after this, care should be taken not to build to a greater height than 5 feet or 6 feet in the first instance; and the stuff must be regularly taken out, either from the centre of the well, or equally all round. If, notwithstanding these precautions, the well does get out of the perpendicular, immediate measures must be adopted to bring it back to the perpendicular, before the sinking is proceeded with. Previous to building again, upon the 5 feet already built, the top course of the brickwork ought to be removed, so as to insure a thoroughly clean surface for the mortar to adhere to, as the top of the length first built is almost certain to have clay and sand in the joints, which would be prejudicial to the bond and strength of the work, as the workmen, especially in India, could not be depended upon to clean out the joints carefully where required. The second height of brickwork should not exceed 10 feet, and if the stratum through which the well has to be sunk is stiff, then the well must be weighted, in order to carry it down. Rails or iron weights are about the easiest handled for weighting, and are much to be preferred to additional height of building as they occupy less height. It is never advisable to build more than 15 feet at a time, whatever depth the wells may have to be carried, as there are two great disadvantages, namely, the additional labour in lifting and excavating the material from the inside of the well, due to the greater height, and also, if the well does happen to get out of the plumb, the great height above the ground will act disadvantageously in getting it back again.

The lime used at the works was made from marl, or, more properly calcareous clay, which was found about 2 feet below the surface, in the bottom of a large jheel, or lake. This could only be excavated in the dry season, as the surface of the ground was under water during six months in the year from the rains. When the clay is first dug, it is about the consistency of glaziers' putty, and of much the same colour; but it rapidly hardens on exposure to the atmosphere. The native style of manipulating and burning it is most objectionable. After being excavated, it is mixed with a large proportion of cow-dung, or ooplah, and kneaded into small lumps, which, when quite dry, are packed in a circular form of clamp, with additional ooplah, straw, and rubbish. The whole is then covered with a layer of clay, the fire is lighted, and allowed to burn for some days. It is left to cool for a couple of days and then opened up and the lime taken out, but in a very impure state, as there is a large per centage of ashes mixed with it; and in many cases the natives purposely mix more ashes to increase its bulk for sale. This lime is mixed with an equal quantity of soorkhee, or pounded brickbats, so that the mortar is hardly fit for any building purpose, as it barely contains 15 per cent. of carbonate of lime.

As there was an abundant supply of this calcareous clay within 6 miles of the works, while the only other suitable lime was the Hill limestone, which was of first-rate quality, but at a distance of 60 miles or 70 miles; and as one half of this distance was through the hills, where camels only could be used for transport, thus nearly doubling the cost, it became a matter for serious consideration whether the calcareous clay could be employed. The following is an analysis of the clay, by Professor Murray Thomson, of the Thomason Engineering College, Roorkee:—

| | |
|---|---|
| Moisture | 1·44 |
| Organic matter and moisture | 1·27 |
| Silicious matter and clay | 49·80 |
| Carbonate of lime | 37·01 |
| Carbonate of magnesia | 2·79 |
| Oxide of iron and alumina | 7·69 |
| | 100 00 |

The Author determined to burn it in the same manner as was done at the brick-fields, which eventually turned out most successful. The

marl, while soft, was roughly moulded into bricks. These were stacked to dry for three or four days, and were afterwards burnt with wood in kilns (built of sun-dried bricks made of clay), for fifty or sixty hours, according to the quality of the firewood, and the state of the weather. The flues were then closed with bricks and mud, and so allowed to remain for two or three days. On the kiln being opened, the lime bricks were unloaded almost in a whole state, were ground under stones, screened, and carried to the works pure and free from ash or dirt. The mortar was made from one part of ground lime, and one part of clean, sharp sand, excavated from the wells of the pier foundations about 15 feet below the bed of the river in the dry season.

This mortar was used in all the well foundations of the bridge up to the level of low water. It was tested in one of the wells, where part of the brickwork was taken down, after having been built six or eight months, and having been under water during the floods in the rainy season. As a proof of the quality of the mortar, it may be stated that it was easier to break the work as a mass than to separate it at the joints, or beds. Above the level of low water the mortar was composed of white hill lime, and soorkhee, or crushed brickbats, in equal proportions, as it was found that the lime from the calcareous clay lost the greater part of its cohesion when used in work exposed to the vicissitudes of the atmosphere—whether this arose from the frequent changes from dryness to humidity, or from heat to cold, was not ascertained. This occurs with many of the Indian limes, as noticed particularly by Colonel Smith, in his translation of M. Vicat's work on Limes and Cements.

The well sinking for the foundations of the piers and the abutments was completed in little more than two years, which, without deducting any time for building up the brickwork, or for that unavoidably lost by the rise in the river during rains, gives an average rate of 159 feet per month, or in all, 3,800 feet. The time occupied in building the steining of the wells, erecting, taking down, and re-erecting scaffolding and staging for the sand pump, weighting the wells, &c., was equal to that employed in sinking. This would give a little over 300 feet per month, which may be safely taken as an estimate of the average rate of sinking. If cast-iron cylinders had been used, the sinking could have been performed more rapidly, on account of the portions of the cylinders being more easily put together, and owing to the slight bearing surface exposed by the

thickness of the iron, compared with the breadth of the brickwork in the walls of the well. The superficial area of bearing surface would be in the case of an iron cylinder 18 feet, and in that of a brick well 87 feet: the resistance by friction on the outside of both being the same. The total weight of the foundations and of the iron girder superstructure on each well was 420 tons, and the area of the bottom of each well being about 117 feet, the weight was less than 4 tons per square foot. This calculation is based upon an experiment made at the Jumna Bridge, Allahabad, where it was found that on a well with 42 feet of water round it, and weighted up to 10 tons per square foot, it did not sink any deeper, although the weight was left on for some months.

The novelty in the sinking of the wells of the bridge on the Delhi railway was in the use of the Sand Pump* (*Plate* XI., *Fig.* 2). This consists of a wrought-iron cylinder A, having a pump E riveted to it at the top by an angle iron *e*. In this cylinder is a piston F fitting loosely, having a play of about ⅛-inch all round. It is made of lead, and is pierced with small holes, to allow of the escape of the water as it descends, and on the top it has a flap of leather, or of india-rubber. It is protected by plates of iron, ⅛-inch thick, at the top and bottom, and on the sides by an iron ring ¼-inch thick. The piston rod passes through a guide G, and terminates in an eye H at the upper end, to which a chain is attached to work it. The bottom B of the cylinder is moveable, and an upright suction-pipe C is riveted to it in the centre. This pipe projects outwards for a distance equal to its own diameter, and inwards nearly to the top of the cylinder. The moveable bottom is supported by the cramps *b*, turning loosely in the lugs of four stiffening pieces D, riveted to the sides of the cylinder, the cramps being tightened up by the cotters *b′*. At the top are eyes for lifting and lowering the whole apparatus by the slings S. In the cover of the cylinder are twenty four holes *a′*, with hinged india-rubber flaps, to admit of the escape of the water as the sand fills the cylinder; and a large hole, *a*, is cut out of the centre, to allow the pump to work.

The mode adopted for working the Sand Pump was as follows :—A pair of sheer legs was fixed on the top of the well, and held in position by guy ropes ; at the apex, or where the legs were joined, a chain was firmly fixed

* *See* No. CLIV. of these Papers.

holding in position a snatch block, through which the chain passed for lowering and lifting the whole machine. Two beams where placed on the top of the well, with rails forming a road for the trollies (which carried the Sand Pump) to run upon, two of them being used at each well. On commencing work, one trolly was brought over the centre of the well, and the pump lifted clear of the trolly, which was run to one side. The pump was then lowered to the bottom, when the chain attached to the piston rod was worked up and down, by men with ropes attached to the end of the chain, in a similar manner to a ringing engine. In this way water was first drawn through the upright pipe, followed by sand or other material, which fell over the pipe into the cylinder. This operation was continued till the cylinder was quite full, which was known by the piston working stiffly, when the machine was raised to the surface. An empty trolly was then brought over the centre of the well, and the Sand Pump lowered down on to it, the cotters were driven back, and the cramps turned rather more than a quarter turn, which released their hold on the moveable bottom. The cylinder was next raised, leaving the bottom with a column of sand resting on the trolly, which was drawn to one side, and another trolly, with a cylinder bottom cleared of its column of sand, was brought under the sheer legs, and the cylinder lowered on to it and fastened with the cramps and cotters. The whole was then raised a few inches, the trolly, removed back again, the Sand Pump lowered to the bottom of the well, and the same process repeated, so that no time was lost, as while the men were working at the pump down the well, the men at the top were clearing off the material brought up on the moveable bottom of the cylinder. The number of men employed at each well was fourteen; nine working the chain attached to the piston of the pump, two on the top of the well attending to the trollies and clearing away the stuff brought up by the pump, one in charge of a steam hoist, one breaking firewood, and an overseer.

The average rate of sinking, including contingencies, was about 6 feet in eight hours. This rate is extraordinary when compared with the old system of the jham and diver, and will, it is believed, materially reduce the expense of bridge-work in India, as regards the outlay upon labour in carrying out the work. The time also in which the work can be performed will be diminished. This is of the utmost importance from the working season in the beds of the rivers being so short, owing to the

floods. If the low-water work cannot be performed before the commencement of the rains, another year goes by before the work can be completed, as nothing can be done during the rains, and till the rivers fall to something like their dry season level, and then a great deal of time is consumed in removing the silt and sand deposited over the site of works by the river.

The Author has endeavoured to describe the nature of the foundations, and the method adopted in their construction. He will now touch lightly upon the manner in which the superstructure was carried out. *Fig.* 3 is a section of the bed of the river taken in November, 1865, when preparations were being made for setting the curbs of the wells for the foundations of the piers. It also shows the level of ordinary low-water and of the hightest flood experienced during the construction of the bridge. *Fig.* 4 is an elevation of one of the abutments and a portion of a girder, with a plan, at low-water level, of the abutment, with wing walls and counterforts. The wing walls of both abutments were carried well inland on the up-stream side, to prevent the river from scouring into the railway embankment during high floods. The top of the wells was fixed at low-water level, after which the work was solidly bonded through, forming the pier. Up to low-water level, the core of the well was filled with concrete, and on the top of this was built a series of stepped courses, forming a conical centre or a kind of stepped groined arch, upon which the upper portion of the brickwork was built. Six round bolts K, $1\frac{1}{4}$-inch in diameter, two of which are shown, were secured to the iron curb, and were carried up to about 6 feet above low-water, at which level they passed through a concentric ring of flat iron, 6 inches broad and $\frac{3}{8}$ths of an inch thick, and were firmly fixed with screwed nuts. There were three of these segmental rings in each well, at about every 15 feet in height.

The brickwork was continued up to within 4 feet of the under-side of the girder, at which level the holding-down bolts C, of the bed-plates, which were 4 feet long and $1\frac{1}{2}$ inch diameter, were fixed with washers 6 inches square, *Figs.* 5 and 7. *Fig.* 7 shows enlarged details of the bed-plates, &c. Upon the top of the masonry of the pier, thicknesses of felt S were laid to the depth of $\frac{1}{2}$ an inch. The wrought-iron plates A, 9 feet long, by 3 feet 6 inches broad and 1 inch thick, were then placed upon this felt, and the cast-iron bed-plates B upon the top of the wrought-iron plates; and at the moveable end, where the girder E slides upon the rollers C, the

plates were fastened together with the bolts P. At the fixed end the girder E simply rests upon the wrought-iron plate A, which was bedded upon the felt S.

The girders, which were on the single-lattice principle, were riveted together near the site of the bridge. They were then raised on to heavy low trollies, carried on a railway to where they were required, and lifted, by two powerful Wellington travelling cranes, clear of the tops of the piers, and lowered into position. *Fig.* 6 shows a half elevation and section of the girder. C is the end box, and A and B the top and bottom boxes, with the struts and ties connecting them. In the cross section, F shows the frames for joining the two girders together. There are six of these frames in each span, besides a rectangular frame with diagonal bracings at each end, riveted to the end boxes C.

The travellers were also used in lifting the pieces of girder into position for erection. It took eight days to erect and rivet each girder, and about one hour to lift it on to the trollies, carry it about 200 yards, and raise it into position on the top of the pier. The cantilevers E, *Fig.* 6, were riveted to the girders when in position. They were for carrying a footpath on each side, which was protected with a light wrought-iron railing.

The last girder of the bridge was put into place in July, 1868, and the first train ran over on the 16th October, 1868, when the deflection and lateral oscillation were very small. The line is now open for traffic.

I. B.

# No. CCLXIV.

## SURVEY OPERATIONS IN ABYSSINIA.

*Report by* LIEUT. T. T. CARTER, R.E., *of the Indian G. T. Survey.*

THE Survey Party sent from India to accompany the Abyssinian Expedition, with the view of making a geographical survey of the country through which the troops marched, was composed of the officers named below,* and a party of native carriers recruited partly from the Himalayas and partly from the neighbourhood of Poonah, Bombay.

The party was supplied with a large equipment of first class instruments, including Theodolites, Transit Instrument, Chronometers, &c., as well as with smaller instruments for reconnoitering; and all arrangements were made before leaving India, in anticipation of our stay in the country being a protracted one, to enable us to collect a large amount of geographical information, and to devote time to the work. But the circumstances of the expedition prevented our going any considerable distance off the line of march; and therefore our work has been restricted to a survey of the route taken by the force, embracing, as far as Antalo, a breadth of country averaging 25 miles, and beyond, of a less breadth, the country being more disturbed. It is, however, to be hoped, that the results of the survey operations will be considered valuable by geographers, as verifying the observations of former travellers, and laying down an important geographical feature, viz., the watershed of Upper Abyssinia.

The plan of operations suggested by Colonel Walker, R.E., Superinten-

* Lieut. T. T. Carter, R.E., in charge.
" A. E. Dummler, R.E., } Assistants.
" T. H. Holdich, R.E., }

dent Great Trigonometrical Survey of India, was to measure a base line near the coast, and carry on a regular series of triangles along the line of country through which the troops passed ; to observe to, and fix by intersection, a sufficient number of prominent peaks by means of which to sketch in the topographical details of the country by the use of the Plane Table, the method of surveying adopted in the topographical surveys of India, permitting the details of configuration of the country, the positions of towns and villages, the courses of rivers, &c., to be noted more rapidly than by any other process.

We landed at Annesley Bay, on the 8th of January, 1868 ; it was the 15th before carriage was obtainable, when we marched to Kumayli and commenced operations by measuring a base line of about three miles in length ; observations were taken from four stations, and a sufficient number of peaks fixed to enable the plane tabling of the country between Annesley Bay and Senafé to be taken up by Lieutenant Holdich.

It soon became apparent that to carry on a continuous triangulation, to plane table the country, and at the same time to keep pace with the force, was impossible. To have done so would have entailed our encamping at considerable distances from, and remaining away for days from, the permanent posts established along the line of march, and would have necessitated our carrying more supplies than we had carriage for (as nothing was obtainable from the inhabitants).

The inhabitants were independent and suspicious, even to the head men attached to us by the political officer, and they had the same opinion of a Surveyor as all other uncivilized people in whose country I have worked, viz., as a person to be watched with suspicion, and up to no good. In this light our friends the Shohos looked on us; they were not good walkers, and decidedly objected to the amount of physical exertion entailed by their accompanying us on our work. With us, it was our object to reach the highest peaks from which a good view of the surrounding country could be obtained, with them to prevent our doing so. One day I was informed that the Sultan (I conjecture that this must have been some Egyptian official) had been in those parts, but that he never showed any desire to go up these steep hills, and look about him with a telescope as we did, and I inferred that they considered it objectionable our doing so. I mention these circumstances as we were entirely dependent on these men for guidance and information, especially in ascertaining the whereabouts

of water, which in these hills is exceedingly scarce, and only to be found where the natives have scooped away in the beds of the ravines, thus obtaining a scanty supply for themselves and cattle; of these puddles they were naturally very jealous. These remarks refer to the country between Senafé and the coast, and I mention them to show the difficulty there would have been in carrying on a continuous triangulation in this part, and the time it would probably have taken.

Lieutenant Holdich has the credit of plane tabling this difficult piece of country, under these unfavorable circumstances, and his report on the same is herewith attached (Appendix). Time and circumstances not permitting a continuous series of triangles being carried on, and at the same time being unwilling to give up the method of surveying by means of the plane table, the only plan that occurred to me was to measure base lines at different points along the line of march, and from each of them to commence a fresh set of triangles, and intersect and fix prominent peaks by which the plane table might be worked. The geographical positions of the ends of these base lines were determined by their being connected together by a traverse line, and thus referred to the initial station at Mulkatto, Annesley Bay. Observation were taken at one end of each base for latitude, and thus a check obtained on the position the traverse gave; the bearing of each base line was determined by observations to ascertain the sun's azimuth, and the angle between sun and referring mark. Lieutenant Dummler connected the north end of the Kumayli base line with the west end of the Senafé base (measured on a plain a little south of Senafé Camp); that there was no great discrepancy in the traverse may be seen from the position it assigns to Senafé Camp. By Traverse, latitude 14° 42′ 35″, longitude 39° 26′ 7″; by Observation, latitude 14° 42′ 33″, longitude 39° 26′ 1″.

The latitude by observation is the result obtained by circum-meridian altitudes of a pair of stars, one north and one south of the zenith; the longitude, the mean result given by three chronometers rated at Bombay, and their error on Greenwich known.

The Senafé base was about three miles in length. Observations were taken from six stations in its vicinity and 24 points fixed; by means of these points, the whole of the country between latitude 15° and latitude 14° was sketched (a most interesting portion of the highlands of Upper Abyssinia, being the watershed), fixing the heads of the Agoritah, Hadàs,

and Kumayli nullahs or ravines which carry off the drainage to the Red Sea at Annesley Bay, to the north; the Maini Baltu, Gaberta, &c., that drain into the Mareb to the west; the Mai Muna and other streams that drain toward the Red Sea to the east; and the point where the drainage begins to run southward, as shown by the Haussen and other smaller water-courses south of Adigrat, which drain into the Takazze, and assist in causing the sudden flooding of the Nile, mentioned by Sir Samuel Baker. I believe that, during the dry season, the majority of these water-courses are dry, except where the water of the previous rains has remained in some of the deeper pools, but that, immediately on the rain falling, about the beginning of June, they become considerable sized streams.

The following prominent mountains fixed by other travellers come into this portion of the Map.

I have drawn out a list of comparisons between our results and those of M. D'Abbadie, whose positions of the same have, I believe, been determined by triangulation. M. D'Abbadie's geographical researches in this part of Abyssinia seem to have been very great, and I have no doubt but that this comparison of results of a few common points will be of interest to those who may read this Report.

| | | ° ′ ″ | | ° ′ ″ |
|---|---|---|---|---|
| Mount Guddam ... ... | Latitude, | 15 24 14 | Longitude, | 39 33 23 |
| Ditto. By D'Abbadie ... | " | 15 24 42 | " | 39 34 37 |
| Mount Tuhuili ... ... | " | 14 46 29 | " | 39 6 16 |
| Ditto. By D'Abbadie ... | " | 14 46 21 | " | 39 7 22 |
| Mount Kisat ... ... | " | 14 40 12 | " | 39 20 10 |
| Ditto. By D'Abbadie ... | " | 14 40 7 | " | 39 21 15 |
| Mount Zéban Sifra (Gonda) | " | 14 26 55 | " | 39 37 7 |
| Ditto. By D'Abbadie ... | " | 14 26 35 | " | 39 38 35 |
| Mount Sargen (Dan Salla) ... | " | 14 26 25 | " | 39 31 44 |
| Ditto. By D'Abbadie ... | " | 14 26 1 | " | 39 33 2 |
| Mount Semiata ... ... | " | 14 11 7 | " | 38 59 15 |
| Ditto. By D'Abbadie ... | " | 14 11 0 | " | 39 0 58 |
| Mount Alé'qua ... ... | " | 14 14 23 | " | 39 25 53 |
| Ditto. By D'Abbadie ... | " | 14 13 48 | " | 39 27 6 |
| Mount Seora ... ... | " | 14 44 22 | " | 39 31 18 |
| Ditto. By D'Abbabie ... | " | 14 42 14 | " | 39 35 36 |

This comparison shows that there can be no great error in the geographical positions assigned to these hills; they all agree closely in latitude, and show a constant difference of $1\frac{1}{4}$ minutes in longitude, with the exception of Seora. There are several other peaks and positions common, but I have only noted these as being the most prominent. In this part of

the Survey the positions of no less than 124 villages are fixed, the most important being that of Adigrat; the position of our camp, some 30" north of the village, was fixed by plane tabling, to be in latitude 14° 16′ 53″, longitude 39° 29′ 23″; the village by D'Abbadie was determined to be in latitude 14° 16′ 0″, longitude 39° 29′ 30″; by Ferret and Galinier, in latitude 14° 15′ 57″, longitude 39° 29′ 0″. Our latitude by astronomical observations was 14° 16′ 62″.

On the map, in addition to the names of the villages, will be found the names of those portions of the ground on which they stand, but I was unable to ascertain whether these divisions were for any fiscal purposes; the word "midr" used to denote them, meaning earth, soil. I may here mention that the word "Adi," prefixed to several of the villages, denotes villages in the Tigré language. With reference to the geological structure of this portion of the country the valleys were metamorphic rocks, the out-cropping hills being sandstone, containing a great deal of iron ore. The country for the most part was very bare of trees, except in the neighbourhood of Halai where there are some large forests of very fine juniper trees. The plateau of Kohaito was also well wooded, and well stocked with game. The natives seem to devote their attention more to the cattle, and keep their land chiefly for pasturage; the crops met with were few, but wheat and barley seemed to thrive where sown.

The villages in these parts were mostly deserted, the inhabitants being attracted to the different British camps, a sure market for labor—the people gladly bringing their cattle to be used as beasts of burden.

The donkeys of the country, which are very fine, were also greatly used for the carriage of grain, &c., to the front.

The next portion of the country, traversed by the force, lies between latitudes 14 degrees and 13 degrees. The character of the country is more undulating. It is bare, and the soil is sandy, but produces large quantities of wheat and barley, judging from the amount of grain brought in for sale at the different camps.

The towns or villages of importance are Antalo and Chelikot. The position of the latter had been determined by previous travellers:—

| | | | |
|---|---|---|---|
| In latitude— | Ferret and Galinier made it | | 13° 21′ 51″ N. |
| " | Lefebvre | " | 13° 21′ 0″. |
| " | Ourselves by plane-table ... | | 13° 21′ 50″. |

At Antalo, the third base line was measured, and connected by traverse

with the Senafé base. The latitude of Camp Buyah, by traverse, from Adigrat, was 13° 14′ 9″; the astronomical observation gave latitude 13° 14′ 13″.

The Antalo base was measured by Lieut. Dummler. Observations were only taken from its ends—fixing the high range of hills bearing the names Fingallat, Mejjem, and Garajam, which appears to be the southern boundary of Tigré. Lieut. Dummler was not permitted to visit any of these hills, it not being considered safe that he should do so; and he was therefore unable to extend the triangulation.

From Antalo to Lake Ashangi, the route of the army lay through a more mountainous and difficult country, held by robber chiefs, who were not to be trusted. No officers were allowed to go off the line of march, and consequently the survey of this portion of the country is much curtailed. Lieuts. Dummler and Holdich, who completed the survey of this portion of the route, found it necessary, on more than one occasion, to take precautions to prevent their carriers being molested, which they effectually did with the small native guard attached to them, (10 men,) the only casualty being the loss of all their baggage mules, which were stolen one night.

Having left Lieuts. Dummler and Holdich to complete the work up to Lake Ashangi, I proceeded to re-commence from that point. It was the 26th of March by the time I had measured the fourth or Ashangi base, and had fixed a sufficient number of points to allow of my plane-tabling.

By the 31st, I had traversed along the line of march, as far as Camp Marawah, and had completed the sketching of the country between Ashangi and that point. From Antalo, the country had become very rough and mountainous, the route ascending and descending ranges of about 10,000 feet in height, intersected by narrow valleys, such as the Atsala, Aiba, &c., as far as Lake Ashangi, and then passing over the Womberat and Duffat passes to Marawah. Notwithstanding these natural obstacles, the march of the advancing column had been steady and continuous; and on reaching Marawah, I learnt that, in a few days' time, the Commander-in-Chief would be before Magdala, and that time would not permit me to do more than carry on a theodolite traverse, leaving the hill-sketching to be done on the return march.

The traverse was completed up to the Talanta plateau by the 12th of April; on the 13th, Magdala was captured, and till the 18th I was em-

ployed in making a plan of the position on a large scale, and in connecting my last traverse station on the Talanta plateau with Magdala and the neighbouring heights. The portion of the country between Camp Marawah and the Bashilo river was only traversed by myself. The topographical detail, as shown on the maps between these two points, is taken from the Quarter-master-General's route survey, as I regret to say that my health had suffered considerably from constant exposure and overwork, and I was consequently unable to do any further work for a time.

The return march of the force from Magdala to the coast was hastened as much as possible, as the rainy season was expected to commence in the latter end of May, and no further opportunity occurred of extending the work. South of Lake Ashangi, up to the Takazze, the route of the army lay through Lasta, a rich country, producing wheat, barley, millet (*Halcus Sorghum*), or the *jawar* of India, dwarf beans, peas, and different kinds of pulses, grown in India, as well as chena (*Palicum Italicum*), commonly called *gram* in India.

From the Takazze, the ascent is made to the Wadela plateau, an extensive pasture ground, extending in a south-westerly direction for about 40 miles. Sheep and oxen seemed to thrive very well on this high land, its elevation being more than 10,000 feet above the level of the sea. The most northerly part of the plateau is near Bethor. The descent to the Djedda river and the ascent to the Talanta plateau, as well as the subsequent descent to the Bashilo, are extremely precipitous; but fortunately a good broad road had already been made from the edge of the Wadela plateau to Magdala by King Theodore, for the transit of his heavy guns.

The instrument used for determining the initial longitude at Malkatto was a Troughton and Simms portable transit instrument, with a two-foot telescope. The method of determination was that of Lunar transits.

The longitude of Senafé was determined by connecting it with the initial longitude by traverse; it was also determined by the method of transportation of chronometers, and the two results agree very fairly; but it is to be remembered that during the transit of the chronometers from Bombay to Senafé, they had been stationary for the greater time on board ship. Beyond Senafé I failed to obtain any satisfactory results. The greatest care was taken in moving them; but the fact of their being moved daily, combined, I believe, with change of temperature (the chronometers having

been received from the Calcutta Observatory, where they had probably been lying some time), altered their rates.

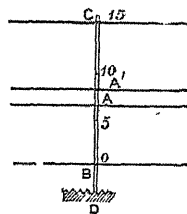
Their rates, moreover, with one exeception, were all large, viz., + 27·8″, − 5·3″, − 8·2″, + 1·0″. The first could not be expected to give any results, and the next two have too large rates.

For the determination of longitude by this method, it is essential that the chronometers should have a small rate, as being small, it is more likely to be constant; further, the number of chronometers should be considerable; and thirdly, the observer should be able to halt occasionally at one place for at least a week, to re-rate his chronometers, which the rapid nature of our march did not permit of our doing. Ours were ship's chronometers. I think that perhaps small pocket chronometers, carried on the person, might have given better results.

In route-surveying of a rapid nature, embracing a large tract of country on either side of the line of march, I think the method of plane-tabling, on points fixed trigonometrically, the best that can be adopted. It has, among other advantages, these,—that the plan is made on the ground, and no field-book is required. It is only effectual where the Surveyor can leave the route to visit commanding positions. The one great qualification that a plane-tabler in a mountainous country should possess, is that of being a good walker, as it is most essential that he should ascend the loftiest elevations from which to obtain a good view of the surrounding country. He must, of course, be a good draughtsman as well.

The Traverse was made with a theodolite, having a mircrometer fitted to the eye-piece, enabling the observer to measure the number of revolutions of the screw-head that a known height subtends,—the angular value of one revolution of the screw-head having been previously determined.

CD is a staff marked 0, 5, 10, 15 feet. The mircrometer has one fixed wire, A, and two moveable wires, B and C, attached to the screw-heads.

In observing, the fixed wire is made to cross the staff at any point, A; and if a 15 feet subtense is being measured, the moveable wires B and C are made to coincide with the marks on the staff at 0 and 15; and number of revolutions 15 feet subtends = rev. AC + rev. AB. In all cases, to prevent mistakes, a second reading was taken, the fixed wire being made to cross the staff, say at

$A^1$: then 15 feet subtends rev. $A^1C$ + rev. $A^1B$ ; = rev. AC + rev. AB, if the observation has been made correctly.

The computation is made very simply by means of a table showing the distance in miles from the instrument to the staff corresponding to the number of revolutions that 15 feet subtend; the 10 and 5 feet marks are necessary for short distances, and the same table is used, by multiplying the revolutions by $\frac{3}{2}$ for a 10 feet staff, and multiplying by 3 if a 5 feet staff is observed to.

At Kumayli, where the base line was measured on ground cut up with numerous and wide ravines, this instrument was used; its accuracy was tested on several occasions, where the ground permitted it, by running a couple of perambulators over the same ground, the comparative results agreeing to the third place of decimals of miles.

This instrument has been introduced by Colonel Walker, R.E., Superintendent, G. T. Survey of India, for mountain route surveying, or traversing over raviney and marshy ground; in the former case, it is particularly useful in enabling the surveyor to avoid all the small bends at which the instrument would have to be put up where measurement has to be made with chain or perambulators.

In all cases, the angle of elevation or depression to the staff were taken, and our distances have been reduced to the horizontal plane.

The whole of our traverse from Annesley Bay to Magdala has been computed out by General Boileau's tables of latitude and departure; the latitude and longitude of points along the route at distances of about a mile apart worked out, and these plotted on the graticuled sheets.

I think this is a better method of plotting a long route, for a small scale map, than plotting the traverse on a large scale, and reducing it by squares or any other method.

The whole of our observations have been reduced by myself, assisted by Lieutenants Dummler and Holdich, at the office of the Director, Topographical Department, War Office, where we have received every assistance, for which I beg to thank the Director, Colonel Sir Henry James, R.E., F.R.S., Lieutenant-Colonel Cooke, C.B., R.E., the Superintending Officer, and Captain Bailey, R.N., by whom the projections were made.

The hill drawing on the fair maps was done by Lieutenant Holdich, R.E., and they were prepared on the scale of two miles to the inch, with

the view to reduction to the scale of four miles to the inch, which was done at the office of the Ordnance Survey, Southampton, Colonel Sir Henry James, R.E., Director.

I would beg to record my thanks to Major Darrah, of the Royal Engineers, who kindly assisted Lieutenant Holdich in taking the observations on which our initial longitude at Mulkatto, Annesley Bay, depends, which were taken after Lieutenant Dummler and myself had left for England.

Corporal Rhodes, of the Royal Engineers, a very intelligent non-commissioned officer, assisted me in the traverse between Lake Ashangi and Magdala, and made himself generally useful while attached to the survey party. I am sorry to say that the health of my assistants as well as my own suffered considerably from the exertions we had to make in surveying so much of the country as is shown in the accompanying map. We felt our time was limited, and it was only by continuous application to the work that we have been able to complete the survey of as much of the country as we have done; I only regret that circumstances did not permit of our doing more.

In addition to Lieutenant Holdich's report on the country between Senafé and Annesley Bay, I have appended hereto the following:* —

1. A list of points fixed by triangulation, with their latitude, longitudes and heights (Appendix B).
2. Observations for latitude, showing resulting latitudes (Appendix C).
3. Observations for longitude, showing resulting longitudes (Appendix D).
4. Observations to determine sun's bearing at different base lines, with resulting bearing (Appendix E).
5. A list of time observations, showing chronometer errors deduced (Appendix F).
6. A list of places and positions determined by traverse (Appendix G).
7. A list showing boiling point observations, with resulting height (Appendix H.)

In conclusion, I have to return my thanks to my assistants Lieute-

* Not printed.—[ED.]

nants Dummler and Holdich, of the Royal Engineers, for their cordial co-operation in carrying out the work on which we have been engaged.

T. T. C.

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APPENDIX.

GENERAL REPORT ON THE COUNTRY BORDERING THE ROUTE FROM ZULA TO SENAFE.

*Topographical Department, War Office, Dec. 14th*, 1868.

The low country between the shores of Annesley Bay and the foot of the ranges of hills which terminate the Abyssinian plateau on the east and north, is a dry, sandy track of partially cultivated ground, which is unwatered during the dry season, when it is subject to the influence of perpetual sand-drifts, and the withering effects of a sun only temporarily clouded by the sand thus raised by the monsoon. At this time of the year, it is apparently deserted by the Shoho agriculturists, although traces of their labors are visible everywhere; and it seems probable that, during the rains, large crops are raised in various parts of the district, particularly in the country south-west of the Gaddam Hills. In the presence of the British force, the cultivation of the ground hereabouts was entirely suspended; and information on this subject was very scantily obtained from the inhabitants. Rain is expected over this country during the months of February, March, and part of April; but these rains appear to be local, and extend from the coast line to a line of about 5,000 feet elevation in the hills, above which they cease. The rainy season commences in the high lands, or plateau, about the beginning of June; and it is during this month that the first torrents generally come down the ravines, and fill the Hadàs and Kumayli rivers, and the beds of the smaller streams in their neighbourhood. Under their influence, the country gradually becomes covered with luxuriant grass and rank jungle. The Shoho agriculturists come out from the ravines and rocks of the lower hills to pasture their cattle, and take possession of the scattered villages, of which the only remnants during the dry season are a few badly built stick huts. There is no indication of much trade amongst these people, and they seem to ignore the art of fishing, although they live on the shores of a sea abounding with fish.

Water probably exists below the surface of the beds of most of the nullahs, and the appliances of the British forces brought it to the surface almost whenever it was needed; but native wells are uncommon, and, except at Futteh, where there are hot springs, the advantage of a permanent supply seems to be unknown. The fact that the natural disadvantages of climate and position are many, and the advantages few, may be inferred from the heap of ruins which now stand for Adulis.

There are five tribes of Shohos (who are all Mahommedans), who at present seem bound, by the ties of peace and common interest, into something like a permanent alliance. These are the Asakari, Asalesan, Ben-Farakatu, Ben-Elelish, and Fakat-harak tribes. The boundaries of their respective provinces are very indefinite: indeed two of them, the Asakari and Asalesan, occupy a hill region a little north of Senafé in common. At present these tribes appears to be banded together in order to hold their own against the Tigré people of the plateau, who are Christians, and consequently their bitter foes. For this frontier service they receive the protection of the Egyptian Government.

Geologically, the whole of this country is volcanic. At Eiromali, a small hill on the extension of the southern spur of the Geddem hills, there are very distinct traces of recent eruption. The water below the surface of the ground is invariably warm, as at Kumayli and Futteh; and there is a report of a volcano existing in constant activity somewhere in a position south of Futteh, about three days' march towards the salt plains. The hills between the Kumayli and Hadàs, and on either side the water, are almost invariably of a trap formation; and their peculiar, horizontal, laminated structure gives them a remarkably rugged and sharp outline, which is, I believe, seen only in the country of Abyssinia. In the beds of the nullahs are large blocks of schist, and of what appears to be granite. Sandstone is, here and there, found above the trap in the neighbourhood of Senafé, and in the ridge east of the Makarra stream.

Villages in all this district are few and far between. The people live in the plains only part of the year; and when they retreat to the hills for water and pasture, they seem to dispense with all artificial habitations, and betake themselves to holes in the cliffs, and caves in the dry beds of the ravines, from whence they only emerge when washed out by the rains. Such houses as there are, are built of sticks and grass in a circular fashion, and stand about 8 feet high, and 10 or 12 feet wide. Sometimes there is

an attempt at a roof; more generally the boughs of which they are composed are bent inwards and tied together at the top. The places where water may be found during the whole year are kept as carefully secret as possible; but there is no doubt that in the lower hills, in the beds of the ravines as they leave the hills, there are plenty of them. In the dry weather, the people of the surrounding district collect and camp in the neighbourhood of these water supplies; and they are visited too by herds of wild animals which exist in the hills, and which come down at night to drink.

Elephants frequent the hills east of the Kumayli route in considerable numbers; their tracks are constant, but they are always on the move during the dry season, and, between midnight and day break, travel many miles through the jungle to and from their watering places. Like all other gregarious animals, in the rains they probably leave the hills for pasture in the plains. Lions make themselves occasionally heard amongst the hyenas at night, but their tracks are rare. They are not common in Tigré, or this part of the country. Five varieties of antelope are common here, including the Koodoo, a magnificent dun-colored animal, standing 14 or 15 hands high; and the Ben-Israel, a small antelope about as big as a large hare, which drops to the smallest-sized shot. Hares are not so common, and are much smaller than the hill variety. Two species of guinea fowl and the common spur fowl are found everywhere. The most prominent and noisy of all the monkey species, viz., the dog-faced baboons, wander in countless numbers over all this region, and everywhere make themselves as conspicuous as possible.

There are three routes to the Abyssinian plateau from the coast of Annesley Bay. The route of the Hadàs river, which was reconnoitred previous to the campaign, is the most westerly. It is undoubtedly the longest, but it is the most generally adopted, as it affords a good supply of water all the year round. No road has been made in this ravine for the greater part of the distance. The ascent to Takonda was partly rendered traversable for military purposes, but is probably now in its original impassable condition again.

The route *viâ* Kumayli was the one adopted for the ascent and descent of the British forces. This route follows the bed of a nullah for the whole distance. Water was plentiful at Kumayli, Sooroo, and Rahaguddy. Wells were made at a place called Maian, in the neighbourhood of Undel.

This route has probably also resumed its primitive condition of difficulty by the action of the last rains.

A third route exists which would be practicable when the two former were flooded, which is at all seasons open to native traffic, but which probably presents more natural difficulties to road-making than either. Its one advantage is its probable passability when the Kumayli and Hadàs ravines are full of water. This route extends across the plains from Malkatto to the hot springs at Futteh; thence to a point where water is always procurable at Imtahàgu, over the easternmost ridges into the Makarra stream. This part of the route is comparatively easy. Beyond this it follows up the bed of the Makarra, which is here broad and open, and presents no appearance of the effects of a torrent during the rains, to the eastern foot of the Maruglu range, which is in occupation of the Fakat-harak and Bethasaba tribes. The Marugla pass is steep and difficult, but from the Maruglu range it is said to be possible to reach Senafé without descending into the Kumayli pass. The easier route, however, is by a small stream called the Garadaf, into a narrow, open plain in the pass, about a mile and a half above Undul wells; and thence by Rahaguddy to the plateau at Senafé, or by the village of Undul to Takonda.

T. H.

## No. CCLXV.

## LAW COURTS AT KURRACHEE.

The building now used for the Law Courts at Kurrachee was designed by Messrs. Scott, McClelland and Co., Architects, practising at Bombay. It was erected by the Directors of the old Bank of Bombay for the accommodation of the Kurrachee Branch of that institution. The contractor employed was Mr. W. Ford, formerly of Kurrachee.

The foundation and superstructure are of stone and lime masonry throughout, and all the woodwork is of Moulmein teak. There is nothing in the construction that calls for special remark. The cost of the site, of raising the level of the ground within the enclosure, and of the building and out-houses, amounted to Rs. 1,50,000. When the affairs of the Old Bank of Bombay were being wound up, this building was offered for sale, and the Bombay Government obtained it for Rs. 85,000, that amount having been sanctioned for the erection of a new Court-house.

The Building was found to be suited for the purpose for which it was purchased, and no expenditure had to be incurred for either alterations or additions.

P. P.

# No. CCLXVI.

## SCANTLINGS OF TIMBER FOR TRUSSED ROOFS.

*Notes and investigations of different methods of determining the Scantlings of Rafters for a Queen-post Truss.* BY PETER KEAY, *Head Master, 2nd Department Thomason College.*

A NEW edition of the College Manual on "Carpentry" being required, I was desired by Colonel Medley, R.E., to revise and correct such portions of the text as seemed to require it; and to look after the work generally while going through the press. While doing this, a question arose as to whether the scantling of the rafter of a truss should be determined by the *thrust*, acting in the direction of its length, or by the *cross strain* upon the different pieces of the rafter, between their several points of support; and referring to other books treating of the same subject, there appeared to be considerable differences in the results given, it being in some cases difficult to understand on what principle or by what method the results were obtained.

On this account, and as the subject is one of considerable practical importance, Colonel Medley desired me to work out a few examples, illustrating the different methods of calculation, and giving a comparison of the different results so obtained. Those for the Queen-post truss will be found in the adjoining table; for the King-post truss there appears to be no necessity for any particular investigation, as the scantlings of rafter obtained for it, by the two different methods of *thrust* and *cross strain*, are very nearly the same, for ordinary slopes of roofing.

The following Table, with the notes and investigations attached, if not otherwise useful, may at least serve to draw attention to the subject, and so help to a correct solution of the problem, as regards a useless waste of material on the one hand, and risk of failure, through the opposite fault, on the other hand.

It might be thought that such an important subject as this would have been correctly determined by this time ; but it appears from the great variety of results given in the Table, that this is very far from being the case, and that even in standard works, either empirical rules are laid down, or loose reasoning employed which is simply copied by other writers without any attempt at original investigation. In so recent and excellent a work as "Newland's Carpenters' and Joiners' Assistant," scantlings are given, (on Tredgold's authority,) which totally differ from either those given in his Tables, or those obtained by his Formula.

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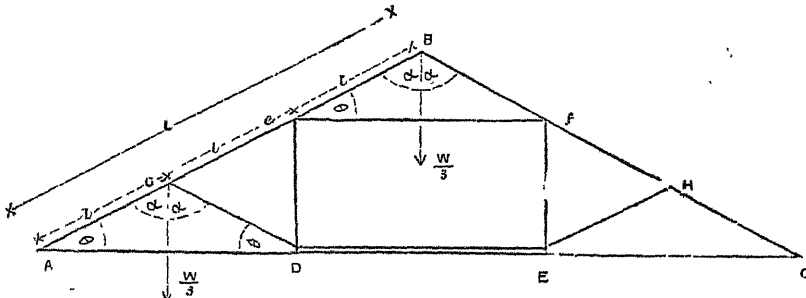
In the following investigations, let W = the weight of roofing supported by one rafter of the trusss ; and $w$ represent the weight of the several pieces of the truss supported at the point $e$—(*see* figure) ; then if $T_3$ represent the thrust on the foot of the rafter, at GA, we have $T_3 = \left(\frac{5\,W}{6} + w\right)$ cosec $\theta$ ; $\theta$ being the angle of inclination of the roof.

There is no necessity, I believe, to enter into any further details of the investigations or formulæ used, as they must be familiar enough to any one interested in such subjects, and may be referred to in the Roorkee Treatise on Civil Engineering.

In the Table some curious results may be observed. In the third

heading for instance, the depth obtained is generally much greater than the corresponding depth given in the second heading, although the breadth given in the second heading was the value taken for $b$ in the formula for $d$ in each case in the third heading; and the sectional areas of the scantlings in the third heading are so much greater than those in the second heading, that it is difficult to understand how the latter could have been calculated by Tredgold's Rule, although they are given in Tredgold's book.

Again, the sectional area obtained for the rafter for span 40 is *less* than that got for span 36. This appears to be due to the loose method of *assuming* the value of $b$ at haphazard, instead of making $b$ bear some fixed ratio to $d$, such as $d = b\sqrt{2}$. It is easy to see that a small decrease in the value of $b$, in the above formula (heading 3) would give a great increase to $d$. For instance, if $b$ were to be decreased from 5 to 4, the result would be to very nearly double the value of $d$, and so give a greatly increased sectional area.

Tredgold appears to calculate his scantlings for *yellow fir* generally, and in calculating the value of E from the results of his experiments on six specimens of that timber, they are as follows:—$\left[E \text{ being} = \frac{L^3 \times W}{b \times d^3 \times \delta}.\right]$
$E = 3502; 4176; 3844; 3625; 4469; 4531$.

The mean of these values of $E = 4024$,

In comparing Tredgold's Rule, as given in heading 3, with the formula for Deflection, as given in heading 6; if we take $66\frac{1}{2}$ lbs. as the weight of the roofing per superficial foot; the slope, 27°; and the timber, Fir, whose value of $E = 4024$; and make $d = b\sqrt{2}$ in each case; then, if we reduce to its simplest form the expression for $b$ in each ease, getting $b$ in terms of S, the span of the roof in feet, we find as follows; the trusses being 10 feet apart.

By Tredgold's Rule, ... ... $b = \cdot3519 \times \sqrt[4]{S^3}$

By formula for Deflection, ... $b = \cdot3038 \times \sqrt[4]{S^3}$

From these results it appears that the breadth got for the rafter by Tredgold's Rule, is to that got by the formula for Deflection, in the ratio of about 7 : 6.

Comparing the sectional areas of the rafters as obtained by the three methods of Deflection, Tredgold's Rule, and Thrust; they appear to be in the ratio of 1 : 1·48 : 2·00 for the span of 32 feet; and in the ratio of 1 : 1·39 : 1·72 for the span of 45 feet.

It would appear then that the scantling of the rafter should be determined by the formula for Thrust, as given in headings 7 and 9; at least this is the conclusion one would come to on first looking at the results obtained in the Table. It may appear, doubtful, however, whether it is advisable to accept these conclusions unquestioned, owing to the following considerations.

In the first place, if we examine the formula for the sectional area of the rafter as given in headings 7 and 9, it is evident that the area depends directly on the value assumed for the Factor of Safety. Under ordinary circumstances, for a steady load, or pressure, it is usual to take (10) as this factor, but it appears doubtful whether, in this case, a smaller number may not be used with safety, for the following reasons:—

The weight assumed for the roofing, per superficial foot, includes 40 lbs. as an allowance for the effects of high wind. Now supposing such a force to act with its full effect, it can only do so on rare occasions, and for brief intervals of time; and such being the case, the timber might, with perfect safety, be subjected to a much greater strain than it could safely bear, were the strain a permanent one.

Again, suppose the wind to blow with a force of 40 lbs. per superficial foot; still, the direction of the wind is, *roughly speaking*, horizontal, so that its effect upon a sloping roof would be reduced in the ratio of 1 : $\sin \theta$; $\theta$ being the angle of inclination of the roof. That is, if the wind act with a force of 40 lbs. per superficial foot upon a vertical surface, it will act with a force of only 20 lbs. on a roof inclined at an angle of 30°.

It may be useful, with reference to the above remarks, to determine what Factor of Safety it would be necessary to use in the formula for Thrust, so as to give the same sectional area for the rafter as is obtained by the formula for Deflection.

To do this, suppose we take the results in headings 8 and 9 for a span of 40 feet. The value of $T_3$ in this case is 39,717 lbs., and the value of $c$ for sál timber, is 8,500 lbs. Take $n$ as the factor of safety, and as the sectional area is to be 35·63, we have area $= n \times \frac{6\ T_3}{5\ c} = 35{\cdot}63$.

$$\therefore n = \frac{5\ c \times 35{\cdot}63}{6 \times T_3} = \frac{5 \times 8500 \times 35{\cdot}63}{6 \times 39{,}717} = 6{\cdot}354.$$

That is, if we take the factor of safety between 6 and 7 we shall get the same sectional area for the rafter by the formula for Thrust, that

we get by the formula for Deflection; and considering the circumstances referred to above, there seems no reason why we may not take it of this value instead of 10, as it is in the calculations for Thrust in the Table.

By comparing in the same way for the span of 32 feet, as given in headings 6 and 7, for fir timber, and the lighter roofing, the value of $n$ is about 5.

If the foregoing considerations appear reasonable, there seems to be little doubt that the scantlings obtained by the formula for Deflection are quite sufficient for actual practice, and to make them as heavy as they are obtained by the formula for Thrust is to use an excess of material that is not really necessary.

As the load of 93 lbs. per superficial foot, referred to in heading 9, is made up of 53 lbs. of a permanent load, and 40 lbs. for the effects of high winds, the sectional area of rafter necessary to meet the thrust due to each of these weights or forces might be calculated separately; taking 10 as the Factor of Safety for the permanent load, and (say) 6 as the factor for the occasional strain due to high winds.

Calculating out the areas separately in this way for the spans of 32, 40, and 46 feet, the results are as follows:—

| | | |
|---|---|---|
| For span of 32 feet, sectional area of rafter due to permanent load, ... ... ... ... | = 25·13 | |
| For span of 32 feet, sectional area of rafter due to high winds, ... ... ... ... | = 9·62 | 34·75 |
| For span of 40 feet, sectional area of rafter due to permanent load, ... ... ... ... | = 31·92 | |
| For span of 40 feet, sectional area of rafter due to high winds, ... ... ... ... | = 12·02 | 43·94 |
| For span of 46 feet, sectional area of rafter due to permanent load, ... ... ... ... | = 37·07 | |
| For span of 46 feet, sectional area of rafter due to high winds, ... ... ... ... | = 13·83 | 50·90 |

These areas may be compared with those given in heading 9.

They agree nearly with the scantlings as determined by Tredgold's Rule *modified* (*See* heading 5).

If the force of the wind be reduced in the ratio of 1 : sin $\theta$, it will be about 19 lbs. per superficial foot for a roof whose slope is 28°, or say 20 lbs.

If the calculations be made separately as above, for this reduced force of the wind, the areas will be as follows:—

| | | |
|---|---|---|
| For 32 feet span; sectional area of rafter for permanent load,... ... ... ... ... | = 25·13 | = 29 94 |
| For 32 feet span; sectional area of rafter for high winds, ... ... ... ... ... | = 4·81 | |
| For 40 feet span; sectional area of rafter for permanent load,... ... ... ... .. | = 31·92 | = 37·93 |
| For 40 feet span; sectional area of rafter for high winds, ... ... ... ... ... | = 6·01 | |
| For 46 feet span; sectional area of rafter for permanent load,... ... ... ... ... | = 37·07 | = 43·98 |
| For 46 feet span; sectional area of rafter for high winds, ... ... ... ... ... | = 6·91 | |

These last areas differ very little from those found by the formula for Deflection, as may be seen in heading 8.

It is quite true that the reasons given above for reducing the Factor of Safety for Thrust, apply also to the Deflection, but the object of discussing the matter so far, is merely to show, that the scantlings obtained by the formula for Deflection are quite sufficient for the practical requirements of the case.

The method of determining the scantlings by the formula for Thrust is unsatisfactory for the following reasons :—

When the length of a piece of timber exceeds from 7 to 8 times its least thickness, it will give way by bending, instead of crushing, when subjected to a heavy pressure in the direction of its length; so it is usual to modify the formula according to the proportion the length bears to the least thickness. For instance, the same formula is used for all the lengths not exceeding eight times the thickness, and this is modified again for all lengths from eight to twelve times the thickness; and again for all lengths between twelve and twenty-four times the thickness; and so on.

The truth is, the law relating to this subject is not well understood, and from the nature of the case, it probably never will be; or at any rate not so well as that relating to Deflection.

For this reason, the scantlings obtained by the formula for Thrust are apt to be irregular. For instance, in some cases, for a truss like that in

the figure, the lengths of the pieces $(l)$ are about 11 times, some 12 and some 13 times the thickness; so these, strictly speaking, should be calculated by different formulæ, which would give very irregular results. In fact, the method of calculating by Deflection is more scientific than that by Thrust, because the law relating to the former is better understood than that of the latter.

The following investigation is interesting even if it should not be of much practical use.

To determine the slope the roof must have so that the scantling of the rafter necessary to support the Thrust, may be equal to the scantling necessary to support the Transverse strain.

Suppose the timber to be *Sál*, the weight of roofing 93 lbs. per superficial foot; and let $L = 3\,l$ = length of rafter; and $W$ = weight of roof on one rafter; also suppose the trusses 10 feet apart, and let S represent the span of the roof in feet, then

By formula for Deflection—

$b = \sqrt[4]{l^2 \times \frac{W}{3} \times \cos\theta \times \frac{25\sqrt{2}}{4 \times E}}$, and $d = b\sqrt{2}$, and sectional area of rafter $= bd = b^2\sqrt{2} = \sqrt[2]{l^2 \times \frac{W}{3} \times \cos\theta \times \frac{25\sqrt{2}}{4 \times 4963}} \times \sqrt{2}$

$$= \sqrt{\left(\frac{L}{3}\right)^2 \times 155 \times S \times \sec\theta \times \frac{25\sqrt{2}}{2 \times 4963}}$$

$$= \sqrt{\frac{S^2 \times \sec^2\theta}{36} \times 155 \times S \times \sec\theta \times \frac{25\sqrt{2}}{2 \times 4963}}$$

$$= \sqrt{\frac{155 \times 25\sqrt{2}}{72 \times 4963} \times S^3 \times \sec^3\theta}$$

For the sectional area for the Thrust—(*see* heading 9) it will be necessary to omit the quantity $w$ from the expression for $T_3$, but this will not affect the result much. Doing this, we have the

$$\text{area of rafter} = 10 \times \frac{6\,T_3}{5\,c} = \frac{60\left(\frac{5\,W}{6}\right)\operatorname{cosec}\theta}{5\,c} = \frac{10\,W\operatorname{cosec}\theta}{c}$$

$$= \frac{10 \times 465 \times S \times \sec\theta \times \operatorname{cosec}\theta}{8500} = \frac{93}{170} \times S \times \sec\theta \times \operatorname{cosec}\theta$$

Then squaring, and equating these two values of the sectional area, we have

$$\frac{93^2}{170^2} \times S^2 \times \sec^2\theta \times \operatorname{cosec}^2\theta = \frac{155 \times 25\sqrt{2}}{72 \times 4963} \times S^3 \times \sec^3\theta$$

$$\frac{93^2}{170^2} \times \text{cosec}^2\,\theta = \frac{155 \times 25\sqrt{2}}{72 \times 4963} \times S \times \sec\theta$$

$$\frac{\sqrt{1 - \sin^2\theta}}{\sin^2\theta} = \frac{28900 \times 155 \times 25\sqrt{2}}{8649 \times 72 \times 4963} \times S$$

$$= \cdot 05124 \times S.$$

$$\therefore \sin\theta = \sqrt{\frac{-1\cdot + \sqrt{1\cdot + \cdot 010504 \times S^2}}{\times \cdot 07247 \times S}}$$

If we take $S = 32$, we get $\sin\theta = \cdot 67202$
$= \sin 42^\circ\ 13'$

If we take $S = 40$, we get $\sin\theta = \cdot 6190$
$= \sin 38^\circ\ 15'$.

If the slope were to be increased much above these angles, the Transverse strain would decrease, and vanish as $\theta$ approached to a right angle; and the Thrust strain would approximate to the value of $\left(\frac{5\,W}{6} + w\right)$ only, because cosec $\theta$ decreases as the angle $\theta$ increases, and ultimately becomes unity when $\theta$ is a right angle.

It appears then, from the above, and former investigations, that for very high, as well as very low slopes, the scantling of rafter necessary to support the Thrust will be greater than that for the Transverse strain.

From a consideration of the whole subject then, the practical conclusion that seems to be suggested is that,—In ordinary cases it will be sufficient to determine the scantling of the Rafter of a Queen-post Truss by the formula for Deflection, given in the heading No. 6; but that for very high, or very low slopes, the scantlings should be determined by the formula for Thrust, as given in heading No. 7.

For a King-post Truss, the Thrust on the rafter is much less than it is in the case of the Queen-post Truss,being only $\frac{3\,W + 2\,w}{4}$ . cosec $\theta$: so that the scantling of rafter for a King-post Truss, as determined by the method for Deflection, will be quite sufficient to support the thrust also.

P. K.

# No. CCLXVII.

## BRICKMAKING BY MACHINERY.

By W. Eckstein, Esq., P. W. D.

The manual process of brickmaking is not an economical one.

Machinery has been introduced to supersede the present system, which has continued the same almost from the days of the ancients; whereby the manufacture of bricks has been converted into a regular factory system, independent for the most part of seasons or weather.

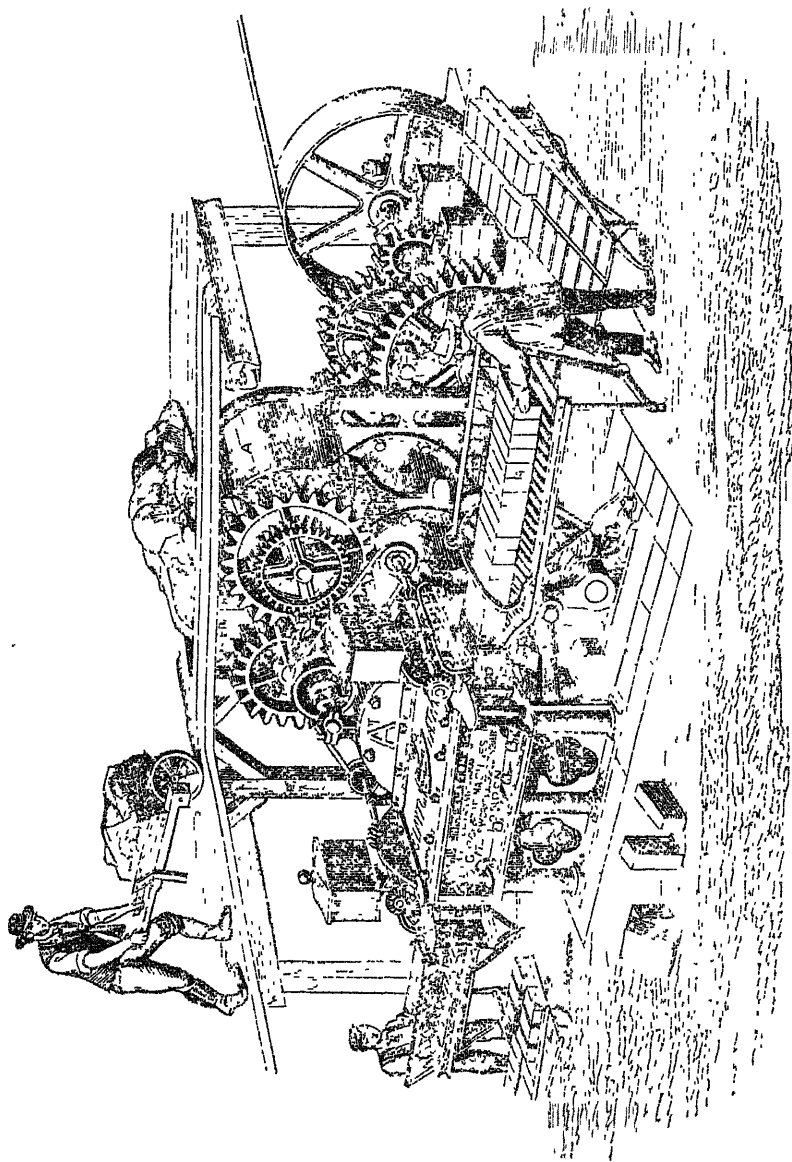
There are two primary systems for making bricks by machinery, viz., first, that for the compression of dry earth; and, secondly, that in which the earth is required to be in a damp or plastic state. For both systems machines have been extensively used and patronized according to prejudices.

In the dry earth system generally, the machinery is more complex, cumbrous and expensive, than in the moist earth system; the motive power required is therefore greater; also as compressing machines are worked with comparatively abrupt concussive and severe strains, the whole must be very heavy or be liable to fracture; the plant also for grinding, pulverising and drying the clay previous to its compression into bricks, is an additional heavy expense. It is generally considered that bricks made on this system are denser than those made in the ordinary way, but the reverse is the fact. And also that by using dry clay a considerable saving is effected; but on the other hand, the plant necessary to reduce it to a fit state for use is a primary heavier outlay.

The moist system may be divided into two modes of procedure, under

differing and conflicting principles. The first, that suggested by the hand process, is compression, the clay being forced into metal moulds either singly or in groups. Machines have been used for the compression of plastic clay, and to fill or force clay into a brick mould is a simple matter; but to do so by mechanical means rapidly and continuously, so as to effectively fill the mould, and also to give an easy and rapid delivery of the moulded brick, without injury to the corners, entailing constant cleansing and lubrication of the mould, have proved extraordinary difficulties.

The second is that of expression, the clay being forced through a stationary die or plate, which will uniformly consolidate and shape it during its passage. In forcing clay through a rectangular orifice, the corners of the issuing mass of clay, having to encounter a greater frictional resistance than any other part, are liable to be torn away, and left ragged and broken. To overcome this difficulty, many experiments have been tried, some with lubricating substances, which were applied to the die when the clay was issuing from it; however, it was soon evident that these were of little use, and would not overcome the difficulty, besides being costly. It was also tried to remedy this defect, and with some success, by filing cores in the centre of the orifice, which tended to equalise the friction, but by this means only perforated or tubular bricks could be produced. It has, however, been overcome by constructing a die with rotary sides, the mechanism of which ensures clean and well defined angles to the bricks. By giving them revolving sides, or friction rollers as it were to the die orifices, bricks are turned out in such a state of stiffness, that they may be walled up several courses high after leaving the moulding table; and, consequently, we can dispense with three-fourths of the area generally required for drying and hacking, which also has the advantage of preventing the loose soil from adhering to the under surface of the brick, as there is no necessity to floor the bricks.

The machines to be described combine the three principal mechanical operations necessary for brickmaking. Machines are essential where the clay is at all stony, or for mixed earths and hard unsoakable marls, which substances require to be passed through a roller mill, and finely crushed, in order to bring them to a fit state to mix with the general mass of clay, before it passes into the pug-mill, and thence to the moulding chamber. Such soil could not be worked into bricks by hand, unless under great expense for washing and picking.

The above engraving is a brickmaking machine combining the three processes of crushing, pugging and moulding. First, the clay is brought by wheel-barrows, and tilted into the hopper at the top of the machine, between a pair of crushing rollers, A, A, which are fed by a self-acting feed or crammer shaft, forcing the clay between the rollers by which the mass is crushed: the rollers by proper set screws can be adjusted to any required width.

Second, underneath the crushing rollers, and in connection, is a horizontal pug-mill, B, in which a shaft revolves, with knives keyed on it, arranged in the form of a screw. By the screw action of these knives, the clay is thoroughly mixed and forced to the other end *b*, of the pug-mill, from which it is carried forward into the moulding chamber, or rectangular box C.

Third, in this box a reciprocating piston moved by a rack and pinion motion underneath, forces the clay alternately from either end through two roller dies, D, D, in a continuous rectangular bar; which is sufficient to produce from 8 to 12 bricks edgeways, the width of the clay being the length, and the thickness the width of the bricks required. If the piston be supposed to be moved towards one end of the moulding chamber, the hollow in the rear of the piston is supplied by the pug-mill shaft as fast as the piston advances; therefore, the whole time, the clay is under a uniform pressure, whereby very important objects affecting the quality of production have been secured, more especially in regard to size and density. When the piston reaches the end of the box, it is reversed, and commences to force the clay out of the other end; whilst this bar of clay is divided into bricks and carried away, each delivery giving just sufficient time to divide and clear the bricks, before commencing delivery again on that same side; so that the bricks, without loss of time, are turned out alternately during the day.

As the success of the machine depends greatly on the arrangement of the rotary dies D, D, they have been drawn to a large scale *Plate* XIV., *Fig.* 1 and 2. The following is a short explanation of the figures *a*, *a*, *a*, is one casting, and is a frame and support to the whole; it is fixed to the end of the machine by bolts *b*, *b*, through holes in the back of *a*, *a*. The upper and lower sides *c*, *c*, of the orifice are made of brass, in order to stand as long as possible; two rollers *d*, *d*, covered with fustian cloth and bound with brass, form the other sides of the orifices, and are fixed vertically by the spindles *e*, *e*, being movable in the bushes *f*, *f*; these receive motion

by bevel gearing from the horizontal shaft $g$, which is supported in the bearings $k$, $k$, and driven by a strap on the pulley $h$, keyed to the shaft $g$; the leather strap is connected to a convenient shaft of the machine. It will be seen that, on turning the pulley $h$ in the direction of the arrow, the rollers will be turned in opposite directions, and thereby greatly assist the clay to leave the machine.

Above the die is a large water box, supported on a cast-iron standard; the water is brought by an iron pipe fixed in the bottom with a screwed end and backnut, and then branches right and left by a T piece to the outer edge of the rollers; at the ends of these branches, is a small brass cock, to regulate the supply of water, and to allow it to drip on the top edge of the rollers; this causes the clay to leave the rollers with a perfectly smooth face.

By referring to the section, *Plate* XIV., *Fig.* 2, the advantage of this roller arrangement is at once seen; the rollers $d$, $d$, not only avoid great friction, but compress the clay while it is being forced forward by the piston through the orifice, thereby producing a solid bar of clay with very clean arisses, which then moves forward in a horizontal position on a table or cutting frame, consisting of wooden rollers covered with similar cloth to the vertical rollers $d$, $d$, and with iron spindles, revolving by the friction of the clay as it advances. This bar of clay is the length and breadth of a brick edgeways. It will be noticed that the rollers $d$, $d$, are slightly tapered towards the top (in the drawing rather exaggerated); this is just sufficient to allow for the spreading of the clay on the bottom side passing along the rollers; the clay when drawn to the full length of the table, is ready to be cut into the required thickness for bricks; this is done in the following manner, while the machine is delivering a similar bar of clay on the opposite side. Between the rollers is a series of strained steel wires, fixed in a frame, movable on two centres underneath. By passing this frame smartly from one side to the other of the bar of clay, it is thereby cut into so many bricks the thickness required.

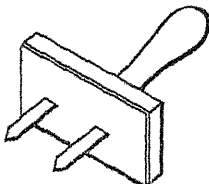
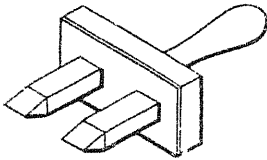



*Fig.* 1.

There are various ways of taking off the bricks; some use small leather pads fixed on the fingers by a small loup, presenting a smooth surface to the brick, or solid bricks are sometimes removed with a fork as shown in *Fig.* 1, the two prongs being made of sheet iron

and firmly fixed into the handle, these prongs are forced into the brick and then it is lifted off. In the case of hollow bricks, a fork is used with two or more wooden prongs, tapered at the ends as in *Fig.* 2, these are inserted in two of the perforations and the brick lifted off. The fork is used in the right hand, and a pallet board taken in the left; after the brick is raised, it is put against the pallet board and turned horizontally; then the fork is withdrawn and the brick left on the pallet, when it is put on the wheel-barrow and taken away to the hacking ground.

*Fig.* 2.

This machine is capable of turning out 30,000 bricks a day with proper attention, so that the bricks do not fall off the machine and become spoilt; 25,000 is the least average with a ten-horse power engine; two smaller sizes, worked by steam, horse, or water power will turn out from 10 to 20,000. These machines will make solid or perforated bricks of any description, viz., cant, or splayed bricks for plinths; weathered, and throated copings of several sizes; round copings; ogee moulded, or quarter round nosed bricks; wedge shaped for culverts; compass, or curved bricks for lining shafts and wells; air bricks for ventilation; damp proof course to prevent damp rising in walls; drainage and gutter bricks for wash-houses; also paving, roofing, and drainage tiles of all descriptions. *Fig.* 3 shows how the cores are fixed for perforated bricks, *Fig.* 4 is a cross section of the core itself; these will be understood without explanation.

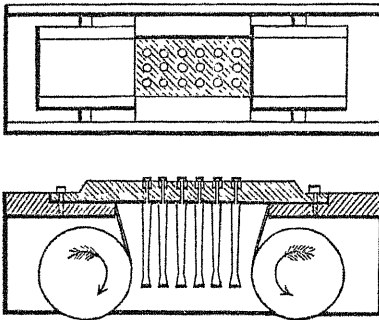



*Fig.* 3.

*Fig.* 4

If we consider the comparison between machine-facture and hand-mould facture, the latter is limited in its productions by size, weight, form, material, cost, &c., whereas the comprehensive variety and scope of facture by machinery is all but without limit, and that by the instrument-

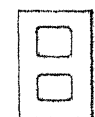
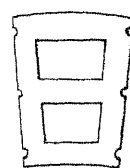
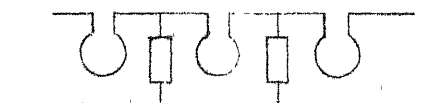
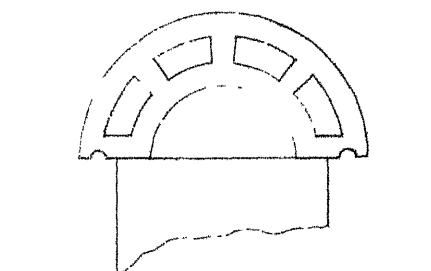
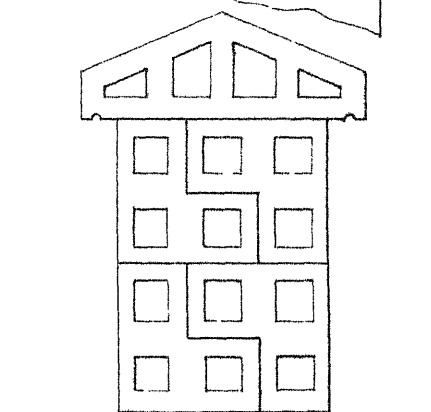
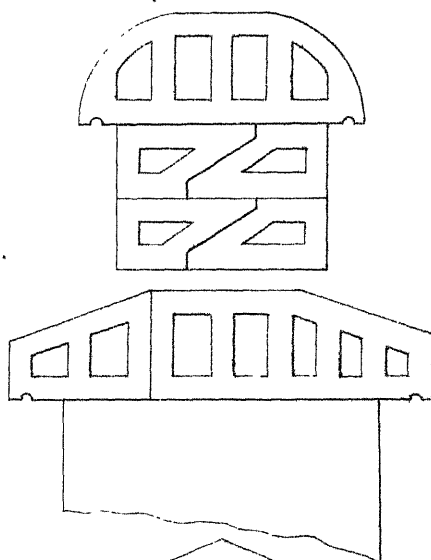
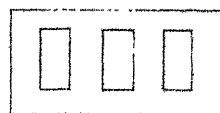
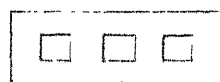
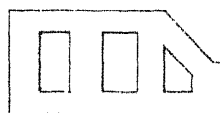
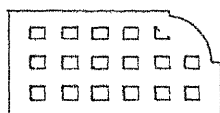
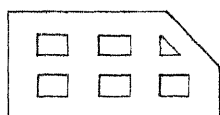
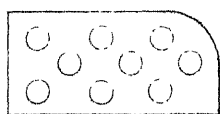
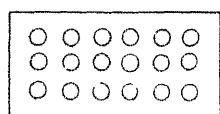
ality of the same machine; also machines are applicable to purposes wholly beyond the powers of the hand-mould brickmaker, viz., to the facture of paving tiles, solid and hollow bricks, of specially large size or form for ornamentation or other purposes, which would involve a mass too great for the handmoulder to lift and manipulate, or forms which hand-moulds could not effectively produce, such as fluted column or pilaster bricks, and large segmental bricks for sewer arching.

The hollow and perforated bricks from their mode of manufacture are more compressed, require less drying, and are better burned with less fuel. It is evident that they would be a first class material for structures in India, as they would not so readily conduct the heat received during the day on the exterior side, to the inner side, to be given out again during the night. And they would be also more economical, as it is supposed that they would require at least one-third less fuel to burn them, than solid bricks of the same size, and also be more equally and easily burnt on account of the homogenous nature of the material.

In burning bricks generally, fuel is about two-thirds the cost of the out-turn from the kilns, *i. e.*, the cost of fuel to burn 1000 pucka bricks, equals twice the cost of getting, pugging, moulding, hacking, loading, firing, unloading and stacking 1000 bricks. Also the out-turn of pucka bricks generally averaging from 70 to 80 per cent. in the case of solid bricks, (unless where special attention is paid, or great experience has been gained) would probably not be less than 90 or 95 per cent., for hollow bricks, as the success of the firing does not so much depend upon the care bestowed on the loading, so that the fire may play freely round the brick: because the fire would pass directly through as well as round the outside, something similar to the fire in a locomotive boiler passing through the boiler tubes; again, the ease and strength, without entailing much supervision, with which they can be loaded in the kiln, would prevent any falling in of the bricks whilst burning and breaking them into bats.

We may therefore conclude that they would save, in fuel $\frac{1}{3}$ of $\frac{2}{3} = \frac{2}{9}$, and 15 per cent. increase in out-turn, say $\frac{1}{6}$, or about $\frac{7}{18}$ altogether—more than $\frac{1}{3}$ the cost of 1000 solid bricks of the same size.

A machine of the above description is essential for the use of contractors requiring large quantities of bricks, who have to use various kinds of earths, of which they must almost of necessity manufacture bricks,—which earth at times by ordinary processes would be quite intractable

BRICK MAKING BY MACHINERY.

—as, for example, in the case of a railway tunnel, viaduct, heavy retaining wall, or fortifications.

Another advantage of these machines, when a contractor is tied for time, or work has to be completed in a short space of time, is that in consequence of the thorough kneading and mixing that the clay goes through, bricks can be made from earth without previous weathering. As an instance of this, on the extension of the Metropolitan Railway at Kensington, passing through a long heavy cutting with a retaining wall on both sides, several bridges, and two junctions, Messrs. Peto, Betts and Waring Brothers, erected four of these largest machines, which averaged about 100,000 bricks a day, and also erected two double circular kilns on Hoffmann's principle. Another example of brick machinery on an extensive scale is at St. Mary's Island, Chatham, where some 25 of the above machines are arranged in a line, worked by the convicts, and the whole in full operation making bricks for the river wall and fortifications.

It will now be as well to consider the quality of the production. "It is a point much discussed by practical men, whether bricks moulded under great pressure are better than those moulded in the ordinary way. They are of denser texture, harder, better faced, heavier, and stronger than common bricks. On the other hand, it is difficult to dry them, because the surfaces become over dried and scale off before the evaporation from the centre is completed. Their smoothness lessens their adhesion to mortar: and their weight increases the cost of carriage, and renders it impossible to lay as many in a given time as those of ordinary weight." With respect to the commonly insisted on quality of "solidity," one of the qualities of a good brick, it is often confounded with the "density or weight." Solidity is essential to a good brick. but weight is not. To increase the former and at the same time to reduce the latter should be the aim of every manufacturer. Solidity depends not on the number and total weight of particles pressed together in a given space, but on the homogeneous incorporation and tenacity of the whole material of the brick, interiorly and exteriorly, to be tested by its powers of resisting pressure, and atmospheric or special influences. For instance, London clamp bricks are among the best bricks, and they are made from a material with a large proportion of breeze or cinders; this is the fuel by which the bricks are burnt, and when these small portions of cinders

are burnt out, the brick must be considerably lighter than where no such fuel is mixed with the brick earth. The imperfectly mixed and concreted particles or lumps, in bricks made by inferior processes, prevent, impair, or destroy tenacity, at the same time adding to weight. The advantages gained by machine-factured bricks are in economy, and larger production of a better article of uniform size with the same amount of raw material, and also a saving of loss in drying, burning and labor.

In order to prove the superiority of bricks made by these machines, the following results of experiments made for the Commissioners of Sewers will speak for themselves, published in the "Builder," 15th March, 1862, since which time many improvements in detail have been effected:—

"All the bricks were bedded (singly and without previous preparation) upon a thickness of felt laid upon an iron fan plate."

| | Pressure to crack Tons | Pressure to crush Tons. |
|---|---|---|
| Good London Gray Stocks, ... ... ... ... | 12·00 | 14·00 |
| The best "Paviors" that could be had, ... ... | 14·06 | 23·00 |
| Red bricks not fully burnt, ... ... ... ... | 13·75 | 25·05 |
| Red bricks ordinary quality, ... ... ... ... | 13·00 | 26·25 |
| 3 White bricks made by Clayton & Co.'s machinery, at Messrs. Brassey & Co.'s works, ... ... | 17·05 | 41·05 |

SECOND TEST.

| | | |
|---|---|---|
| 4 White bricks same quality made by Clayton & Co.'s machinery, ... ... ... ... ... | 16·25 | 41 00 |

"The weight was applied not to a number of bricks in mass, but to each brick singly, distributed over its surface; the resistance made by the machine made bricks to crushing is a good proof of tenacious solidity. In some other tests, 50, 80 and even more than 100 tons have been required to crush these machine made bricks.

It will be, no doubt, at once said that there could be no economy in employing steam machinery in this country where labor is comparatively so cheap. My only reason for writing this paper is to promote one of the most important manufactures of the day, and attract more attention to it, having been engaged for two years in the erection and manufacture of brick-making machinery in its several parts. Every one must be aware of the difficulty of superintending a brick field for a sufficient time daily to see that the brick earth is properly mixed or puddled; therefore, generally, very inferior bricks of differient sizes, with no pretensions to shape, are turned out,—and also the amount of labor lost by chipping a brick square or to a

true face, in other words, either breaking or spoiling it, which is really the case, as the face of a brick should not be chipped at all, as the mould and firing give a finish and glaze to the sides of a brick, which is a great protection to a face wall. "If in the execution of a piece of brickwork, bricks of other shapes are required, it was formerly the practice, and still sometimes is, for the bricklayer to cut the ordinary bricks to the required shape. This practice so destructive to sound bond and good work, cannot be too strongly reprehended *, especially now that there can be no excuse for not making bricks of a great variety of shapes for various purposes."

W. E.

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* "The brick columns, whose failure caused the frightful accident which occurred in January 1848, during the erection of the new buildings at the Euston Square Station of the North Western Railway, were built in this way; the additional cost of bricks made expressly for the work, of such forms as would have bound properly together without any cutting, would have been trifling."

# No. CCLXVIII.

## THE MAURITIUS RAILWAYS—MIDLAND LINE.

BY JAMES ROBERT MOSSE, M. INST. C.E.

*(Re-printed from the Proceedings of the Institution of Civil Engineers for* 1868-69).

THE chief object of this Paper is to give a concise account of the working of the unusually heavy gradients which prevail on the Midland Railway. Before, however, proceeding to this subject, it may be well to notice, briefly, the chief physical features of the island, and the causes which led to the introduction of railways in the colony.

Mauritius is entirely of volcanic origin. The mountains consist of basalt, tufaceous rock, and lava, and have been thrown up on all sides, to heights varying from 2,000 to 3,000 feet above the sea. In the centre of the island, the table-land traversed by the Midland Railway has an elevation of 2,000 feet above the sea, the distance from the coast being about 15 miles. In the northern and eastern parts, the ground rises gradually; but in the southern and south-western portions, the features of the country are exceedingly broken and rugged.

The soil of Mauritius, though unusually fertile, varies greatly in character. In some places and for a considerable area, the soil is deep and entirely free from rocks; while within a short distance, the rock again crops out on the surface without any soil whatever. Throughout a large portion of the island, the soil is covered with loose blocks of basalt and lava of all sizes, which are piled up into parallel rows, 5 or 6 feet apart, and the canes are planted between them.

The extreme dimensions of the island are about 38 miles long by 37 miles broad. Its area is about 706 square miles, of which there are under—

| | |
|---|---|
| Cane cultivation, ... ... ... ... ... | 230 square miles. |
| Planted with maize, manioc, and vegetables, ... | 25 " |
| Forest and pasture, ... ... ... ... | 168 " |
| Waste and uncultivated land, ... ... ... | 282 " |
| Total, ... | 706 " |

For so small an area, the population of Mauritius is extraordinary. According to the returns made on the 31st December, 1866, the population of the the colony then amounted to 341,165, of which about 75,000 resided in Port Louis, the principal port and the seat of Government. The population thus amounts to 483 per square mile over the whole island, or 1,338 per square mile over the land in cultivation.

Sugar-cane is well known to be the principal, it may almost be said to be the only, production of Mauritius. With this exception, the colony raises scarcely anything required for its consumption, but exports nearly its whole product, and imports all articles required for food and for its other necessities. Everything grown in the country is sent to Port Louis for exportation, and everything required on the estates is brought back from that town; hence arises an amount of traffic between the port and the interior unusually great in proportion to the population and to the area of the country.

For the last seven years, the average imports into, and exports from, the Mauritius have been as follows:—

| | Tons | Value. |
|---|---|---|
| Imports, ... ... ... ... | 279,597 | £2,131,408 |
| Sugar exported, ... ... ... | 126,852 | 2,206,196 |
| Total exports, ... ... ... | 215,811 | 2,375,230 |

From these figures the following results are obtained:—

Per Square Mile per Annum.

| | Tons. | Value. |
|---|---|---|
| Imports, ... ... ... ... | 396 | £3,019 |
| Total exports, ... ... ... | 306 | 3,364 |

Per Head per Annum.

| | Tons. | Value. |
|---|---|---|
| Imports, ... ... ... ... | 0·81 | £6·25 |
| Total exports, ... ... ... | 0·63 | 6·93 |

From 1860 to 1866, the average population has been 326,214, the rev-

enue £571,931 and the expenditure £578,969, giving £810 and £820 per square mile per annum, respectively, or £1·74 and £1·76 per head per annum.

From the hilly nature of the island, from the expense of importing mules from France and Montevideo, grain from India, and oats from Australia or the Cape, it will be evident that the best means of conveying these exports to town, and the imports from Port Louis to the interior, soon became a serious question.

Until recently, the sugar from the estates near the coast was conveyed to Port Louis by schooners, carrying from 60 tons to 120 tons each, and from the other parts of the island it was carted to town by mules. These carts conveyed from 30 cwt. to 40 cwt. of sugar each, and required three and sometimes four mules; but in ascending from Port Louis to the districts traversed by the Midland Line, the return load only ranged from 10 cwts. to 15 cwt. per cart. Conveyance by coasters, though cheap, depreciated the sugar owing to its exposure to the damp, and to the losses consequent on frequent transhipments and pillage; while the cartage was, for the reasons given, very expensive, notwithstanding the excellent condition in which the roads are maintained by the Government.

The necessity for railway communication being felt by the local Government, Mr. James A. Longridge (M. Inst. C.E.) was in May, 1858, charged by the Right Hon. the Secretary of State for the Colonies, "to investigate by regular surveys and sections, and by careful estimates, complete as to outlay of capital, annual expenditure and traffic returns, the question, as yet undecided, of the introduction of railways into Mauritius." The Report being in favor of the railway system, the construction of the works was, in May, 1861, authorised by the Imperial Government. For some time, hopes were entertained that the railways would be undertaken by a private Company; but, as no suitable offer was made, it was decided that the works should be carried out by the local Government, the funds being obtained from some large balances of revenue then on hand, and by the issue of one million pounds of colonial debentures, bearing 6 per cent. interest, and secured by a sinking fund. The total sum for which the general revenue of the colony thus became responsible was £78,000 per annum. Mr. Hawkshaw (Past-President, Inst. C.E.), who had previously reported on the railways by order of Government, was appointed Consulting Engineer to the Mauritius Government; and in

September, 1861, a contract was entered into with Messrs. Brassey and Wythes for the execution of the works, which were commenced early in 1862, under the direction of Mr. Walmsley Stanley (M. Inst. C.E.), as Chief Resident Engineer for the Government, and of Mr. J. A. Longridge (M. Inst. C.E.), as Agent for the Contractors.

The North Line, starting from the central station at Port Louis, traverses the northern and the north-eastern parts of the island, through the districts of Pamplemousses, Rivière du Rempart, and Flacq to Grand River, being a distance of 31 miles. The Midland Line, commencing at the same station in Port Louis passes through the centre of the island, by the districts of Plaines Wilhems and Grand Port to Mahebourg, a small town containing a population of about 6,000, and distant 35 miles from Port Louis.

The North Line contains no engineering feature of interest, and the only work of importance on the Midland Line is the Grand River Viaduct already described by Mr. Ridley.* The North Line was opened for public traffic on the 24th May, 1864, and the Midland Line on the 19th October, 1865.

Sufficient land has been purchased for a double line, and the masonry of all culverts and bridges has been built for a double way; but the ironwork for the superstructure of the under girder bridges and the permanent way have only been provided for single line of rails.

The *Rails*, which are laid to the ordinary narrow gauge, are of the usual double-headed pattern, weighing 74 lbs. per yard, fished with plates weighing 11 lbs. each, the sleepers being placed 2 feet apart from centre to centre at the joints, but averaging 3 feet elsewhere.

The *Chairs* are of the usual form, weighing 25 lbs. each, but countersunk at the bottom for a length of 2 inches by 2 inches in width, and by $1\frac{1}{4}$ inch in depth. These chairs have not proved sufficiently strong, quantities having broken through the hollow in the bed, where the metal is about $\frac{7}{8}$ inch thick; so much so that the chairs now ordered to replace them are made of increased strength. The keys have held well; the climate being wet in the hot season, they have not shrunk so as to get loose, nor have they swollen so as to break the lip of the chair.

The *Sleepers* are of Baltic red timber, 9 feet long by 10 inches by 5 inches in section, creosoted with 1 gallon of oil to every cubic foot of

* *See* No. CXXXV. of these Papers.

timber. Some miles of these sleepers have now been in use five years, and few, if any, show signs of decay; nor have they been in the least attacked by the white ants, which destroy all ordinary timber in damp situations, except teak, in the course of two or three years. It should be mentioned that the ballast is composed entirely of broken stone, which keeps the sleepers more than usually dry; and in order to prevent their splitting from the heat of the sun, they are covered with the ballast to a depth of 3 inches or 4 inches. The rigidity of this stone ballast may, probably, in some measure, account for the large breakage of the chairs before alluded to.

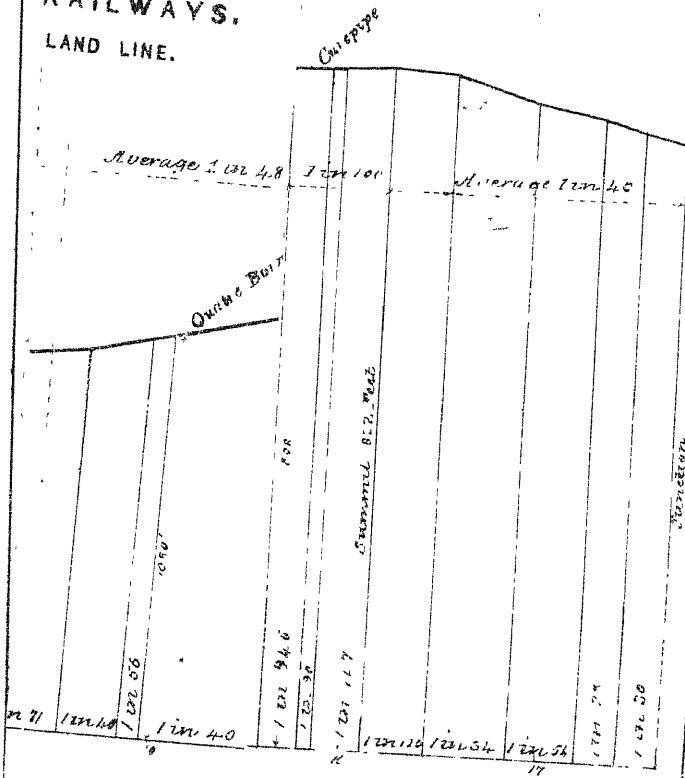
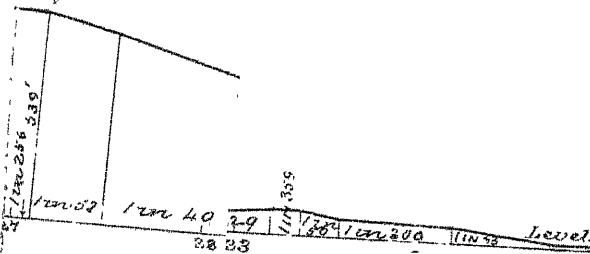
The *Cost* of these railways may be taken as follows:—

| | £ |
|---|---|
| Contracts, .. ... ... ... ... ... ... | 1,038,641 |
| Extra works, ... ... ... ... ... ... | 22,927 |
| Central Station, Port Louis, ... ... ... ... | 40,230 |
| Purchase of land, ... ... ... ... .. ... | 195,544 |
| Engineering and management, ... ... ... ... | 104,084 |
| Electric Telegraph, ... ... ... ... ... | 6,046 |
| Additional rolling-stock, ... ... ... ... | 36,380 |
| Total ... ... | £1,443,852 |

Equal to £21,876 per mile.

For this large expenditure there are many exceptional causes; among others, the construction of the line over the Trou Faufaron, and along the streets of Port Louis to the Caudan, which involved a heavy viaduct and the purchase of valuable town property. The ground also at the Central Station being exceedingly soft, extensive piling was required for the foundations of the masonry and of the turn-tables, &c.

The high charge of £104,084 for management, includes all the expenses connected with the loan, as well as premium of exchange in remitting the funds thus raised from England to the colony.

The unusually heavy character of the *Gradients* on the Midland Line will be understood from the following summary:—From Port Louis to the summit, at Curepipe, there is a rise of 1,817 feet, the distance being about 16 miles; which gives an average gradient of 1 in 46·68; and from the summit to the terminus at Mahebourg, a distance of about 19 miles, there is a descent at the rate of 1 in 55·61. For about 12½ miles before reaching the summit, between Coromandel and Curepipe, the inclination is on an average 1 in 41·17; and thence between the summit and Union Vale, for about 13½ miles, the line falls on an average 1 in 45·06.

The following tabular statement will show these gradients more clearly:—

| From | To | Length in feet. | Rise in feet. | Average gradient 1 in | Total Rise above Port Louis in feet. |
|---|---|---|---|---|---|
| Port Louis, . . . . | Coromandel, . . . | 14,800 | 170 | 87 | 170 |
| Coromandel, . . . | Rose Hill, . . . . | 28,399 | 748 | 38 | 918 |
| Rose Hill, . . . | Phœnix, . . . . | 18,670 | 388 | 48 | 1,306 |
| Phœnix, . . . . | Vacoa, . . . . . | 6,200 | 60 | 103 | 1,366 |
| Vacoa, . . . . . | Curepipe, . . . . | 13,963 | 437 | 32 | 1,803 |
| Curepipe, . . . . | Summit, . . . . | 2,800 | 14 | 200 | 1,817 |
| | | | Fall in feet | | |
| Summit, . . . . | Cluny, . . . . . | 33,063 | 819 | 40 | 998 |
| Cluny, . . . . . | Rose Belle, . . . | 12,124 | 126 | 96 | 872 |
| Rose Belle, . . . | Union Vale, . . . | 25,557 | 625 | 41 | 247 |
| Union Vale, . . . | 32nd Mile, . . . | 12,210 | 180 | 67 | 67 |
| | | | | | Total Fall. |
| 32nd Mile, . . . | Mahebourg, . . . | 18,116 | 67½ | 268 | 0·5 |
| | Total, . . . | 185,902 | | | |

The *Gradients* vary, in ascending to the summit, from 1 in 27 to 1 in 60; having, between these limits, a length of 57,362 feet, and a rise of 1,622 feet. In descending towards Mahebourg, the gradients vary from 1 in 30 to 1 in 60; having, between these limits, a length of 57,805 feet and a fall of 1,556 feet. The steepest gradient is 1 in 27, of which there is an aggregate length of 13,526 feet, with a rise of 499 feet; the greatest continuous length of this gradient being 6,163 feet, and the next longest 5,016 feet. The next in severity is 1 in 30, of which there is an aggregate length of 9,526 feet in ascending, and 7,510 feet in descending; the greatest continuous length being 3,000 feet, and four other lengths averaging about 2,400 feet each. After 1 in 27, the gradient of the greatest aggregate length is 1 in 40, equal to 11,460 feet in ascending, and to 8,967 feet in descending; the greatest continuous length being 4,817 feet, the next in length 3,700 feet, with six other lengths of about 1,700 feet each. Of gradients of 1 in 40 to 1 in 50, there is an aggregate length of 9,050 feet in ascending, and 11,974 feet in descending; the greatest continuous length being 5,300 feet of 1 in 44, with four other lengths of about 2,200 feet each within these limits. Of gradients of 1 in 50 to 1 in 60, there is an aggregate length of 6,900 feet in ascending, and 6,100 feet in descending; the greatest continuous length being 3,300 feet of 1 in 50, with two other lengths averaging 2,000 feet within these limits.

The *Curves* vary from 950 feet radius to 6,000 feet radius, and the lengths of the curves range from 200 feet to 3,200 feet. The ordinary radii are generally from 2,000 feet to 3,000 feet. The following summary shows the least radii which occur on the steepest gradients between Port Louis and Curepipe :—

| Radius in feet. | Length of Curve in feet. | Gradient on which Curve occurs. |
|---|---|---|
| 1,400 | 1,350 | 1 in 100 |
| 1,500 | 1,600 | 1 in 55 |
| 1,600 | 900 | 1 in 27 |
| 1,600 | 860 | 1 in 29 |
| 1,600 | 1,930 | 1 in 30 |
| 2,000 | 1,000 | 1 in 27 |
| 2,000 | 950 | 1 in 27* |
| 2,000 | 970 | 1 in 27* |
| 2,000 | 700 | 1 in 27 |
| 2,200 | 550 | 1 in 27 |
| 2,000 | 1,300 | 1 in 30 |
| 2,000 | 700 | 1 in 30 |
| 2,200 | 600 | 1 in 27 |
| 2,400 | 1,000 | 1 in 27 |

* Reversed curve.

It will thus be seen that 1,600 feet is the sharpest radius which occurs on the steepest gradients of 1 in 27 and 1 in 30, the greatest continuous length of this curve being 900 feet on the former gradient, and 1,930 feet on the latter. The next radius in severity is 2,000 feet on the maximum gradient of 1 in 27, the greatest continuous length of this curve being 1,000 feet. At Beau-Bassin, reverse curves of this radius, 1,920 feet in length, are also found on the maximum inclination of 1 in 27. On descending from Curepipe to Mahebourg, the line from the 17th to the 19th mile may be said to be composed wholly of reversed curves, of which the following are some of the chief instances :—

| Radius in feet. | Length of Curve in feet. | Gradient on which Curve occurs. |
|---|---|---|
| 1,300 | 1,100 | 1 in 31 |
| 1,800 | 450 | 1 in 30 |
| 1,800 | 550 | 1 in 31 |
| 1,800 | 1,700 | 1 in 36* |
| 1,800 | 950 | 1 in 44 |
| 1,800 | 160 | 1 in 44 |
| 1,800 | 400 | 1 in 44 |
| 1,930 | 1,000 | 1 in 30 |
| 2,000 | 800 | 1 in 31 |

* Chiefly.

These 2 miles are considered to be the worst part of the railway to work: for, although the gradients are not so steep as elsewhere, the line is altogether curved, and, passing through woods, it is impossible to see for more than a short distance ahead. The most severe curvature between the 19th mile and Mahebourg is at the 29th mile, where the radius is only 1,400 feet, the length of this curve being 1,980 feet, chiefly on a gradient of 1 in 30. Of curves under 2,000 feet radius, there is an aggregate length of 21,165 feet; of those ranging from 2,000 feet to 4,000 feet radius there is a length of 49,710 feet; and of curves from 4,000 feet to 6,000 feet (the greatest radius) there is an aggregate length of 25,560 feet, the total length of curves being 96,435 feet, and of the straight portions of the line 89,467 feet.

The *Locomotives* furnished under the original contract for working these inclines are seven in number, and of the following description; they are tank engines, having cylinders 16 inches in diameter, with a length of stroke of 22 inches; the wheels, six in number, are 3 feet 6 inches in diameter, and are all coupled, the length of the wheel base being 15 feet. When supplied with water and fuel, these engines weigh nearly 37 tons, and they are worked with a pressure of steam of 120 lbs. per square inch. The load which these Engines are able to convey depends greatly upon the state of the rails; for though there are sand-pipes leading to four wheels out of the six, it is always found that the engines work best when the rail is perfectly dry.

The original engines having been found inadequate for the traffic, subsequently six larger saddle-tank locomotives were designed by Mr. Hawkshaw, of the following dimensions: Cylinders, 18 inches in diameter, with a length of stroke of 24 inches; the wheels, eight in number, are 4 feet in diameter, and are all coupled, the length of the wheel base being 15 feet 6 inches. When supplied with water and fuel, these engines weigh nearly 48 tons, and they are worked with a pressure of steam of 120 lbs. per square inch. The centre pairs of wheels (one of which is the driving pair) are fixed stiff in the frame; but in order to pass easily round the curves, both the leading and the trailing wheels have a play of ¾ inch in each journal; and the joints of the coupling rods, connecting these wheels with the driving pair, are fitted with a ball and socket, so as to allow the requisite motion. Four sand-boxes are attached to the engine-frame, leading sand to every wheel, but although the sand is

of the sharpest quality, obtained specially from the Cape, it is often found impossible to prevent the locomotives from slipping to a serious extent on the steepest inclines. So much is this the case with the first morning goods train, when the rails are wet with dew, that it has been found necessary to extend the time between Port Louis and Phœnix, a distance of 12 miles, from 1 h. 15 m. to 1 h. 30 m., or to a speed, including stoppages, of only 8 miles per hour.

All the engines were manufactured by Messrs. Sharp, Stewart and Co., of Manchester, and work very satisfactorily. The carriages and wagons are all of the best description, similar to those used in England, and were manufactured by Messrs. Brown, Marshall and Co., of Birmingham, the wheels and axles having been supplied by Messrs Lloyd, Foster and Co., of Wednesbury.

There are two Passenger Trains each way daily between Port Louis and Mahebourg, and two additional trains each way daily between Port Louis and Curepipe, the great majority of first-class passengers residing between these points, and travelling, as season-ticket holders, to town and back daily. There are also two through Goods Trains each way daily, and occasionally special Goods Trains when required for that traffic.

The ordinary passenger train consists of four carriages and the break-van. The smaller engines can fairly take another carriage, making six vehicles in all, say equal to a load of 42 tons, and this is as much as can be depended upon, though on many occasions they have hauled seven loaded vehicles, and in some instances eight, weighing in all about 56 tons.

With goods trains, the ordinary number is six loaded wagons plus the break-van, say equal to 70 tons; but with the 5·45 A.M. down-train, when the rails are wet, the load (in order not to detain the other trains) is limited to five wagons, making six vehicles in all, or say 60 tons. These may appear very small loads for engines weighing 37 tons, but it should be remembered that to ascend gradients of 1 in 30 requires fully eight times the tractive force that would be requisite on a level.

The larger locomotives, weighing 41 tons each, will take five passenger-carriages and one break-van, equal to a load of 42 tons, though on some occasions they have hauled eight loaded vehicles, weighing in all about 56 tons. With goods trains, the ordinary load in descending is nine loaded wagons and a van, say equal to 100 tons, though occasionally there have been twelve loaded vehicles, or, say about 120 tons. By

reducing the lead of the slide-valves to one-eighth of an inch, the power of the engines was subsequently increased 10 per cent.

Deducting stoppages, the running speed of the Passenger Trains is about 16 miles per hour, or, including seven stoppages, 12 miles per hour, between Port Louis and Curepipe, where the gradient for the whole distance rises on the average 1 in 45·83; and 15 miles per hour, including four stoppages, from Mahebourg to Curepipe, where for 19 miles the ascending gradient averages 1 in 55·61. This speed is quite as much as can be realized in ascending in ordinary weather. On wet days, notwithstanding all that can be done with sand, the engines slip; and in many cases, on gradients of 1 in 27 and 1 in 30, with the smaller locomotives, the speed has fallen to 4 miles per hour, even with a train of five vehicles, or say, of 35 tons.

The average running speed of the Goods Trains is 12 miles per hour, or, including the frequent stoppages, about 9 miles per hour; and this, as the engines are always loaded to their maximum, is as much as can be attained. Speed over these gradients is of less importance than economy of motive power.

Whenever two locomotives are required with any train, either Passenger or Goods, the second engine is placed in the rear of the train, to ease the great strain on the couplings, and control the vehicles, should any of them break loose. This plan, though open to some objections, has hitherto worked well, and there has been no instance in which the vehicles have mounted the rails in consequence of the pushing from behind.

According to the usual formula, the tractive force required per ton, on a curved line with a gradient of 1 in 27, at a running speed of 6 miles per hour, is found to be 95 lbs. With a load of 100 tons, or, including the engine, of 148 tons in all, 6 miles per hour may be taken as the average speed up 1 in 27. Then, $\frac{\overset{\text{lbs.}}{95} \times \overset{\text{tons.}}{148} \times \overset{\text{miles.}}{6} \times 88}{33{,}000} = 225$ H. P. exerted, or, excluding the weight of the locomotive, it is equal to 152 H. P., and this divided by the weight of the engine becomes 3·16 H. P. per ton of motor. To obtain this tractice force (14,060 lbs.) an effective pressure in the cylinder of nearly 87 lbs. per square inch is requisite; but as 60 lbs. is nearer the average pressure, the tractive force becomes

$$\frac{\overset{\text{ft.}}{4} \times 2 \times \overset{\text{lbs.}}{60} \times \overset{\text{sq. in.}}{254{\cdot}47}}{12{\cdot}566 \text{ feet.}} = 9{,}720 \text{ lbs.}$$

In the former case, the adhesion required would be 13 per cent., and in the latter, 9 per cent. of the weight of the locomotive. Taking the average gradient from Port Louis to Curepipe at 1 in 45·83, the mean tractive force required is 60 lbs. per ton, equal *to* a force of 8,880 lbs. for a load of 148 tons.

The following are the results of a particular trip made on the 12th December, 1867, when the fuel and water were noted more accurately than usual. The distance from Port Louis to Curepipe is 15·65 miles, in which there is a rise of 1,803 feet. The train consisted of ten loaded wagons, weighing 83 tons, and of an engine weighing 48 tons, together 131 tons. The running time was 1 hour 25 minutes, and the average speed 11 miles per hour. The coal consumed on the trip amounted to 986 lbs., giving 63 lbs. per mile, exclusive of lighting; 0·48 lbs. per ton per mile, including the weight of the locomotive; and 0·76 lbs. per ton per mile, excluding the weight of the locomotive. This consumption was at the rate of 696 lbs. per hour; of 39 lbs. per square foot of grate per hour; and of 4·75 lbs. per H.P. exerted per hour. The total water evaporated on the trip weighed 7,888 lbs., so that 8 lbs. of water were evaporated by 1 lb. of coal. The quantity evaporated per hour was 5,568 lbs., giving 309 lbs. per square foot of grate area, and 4·6 lbs. per hour per square foot of heating surface, and 38 lbs. per H.P. exerted per hour. The gross weight of this train being 131 tons, the average power exerted would be

$$\frac{131 \times 60 \times 11 \times 88}{33{,}000} = 230 \text{ H.P.},$$

or, not including the weight of the engine, 146 H.P., and this divided by the weight of the locomotive, is equal to 3·04 H.P. per ton of motor. The coal used on this trip was obtained from the Warattah Colliery, near Sydney, New South Wales, and was of the usual quality; but the evaporation of water per lb. was rather above the average, the ordinary quantity being about $7\frac{1}{2}$ lbs. of water evaporated by 1 lb. of coal.

*Break power.*—With the exception of the first-class carriages, all the others on the railway have a Break on every wheel, worked from the inside. The ordinary Passenger Trains consist of one first, one second, and two third-class carriages, with one break-van; and to these trains Mr. Clark's continuous break is attached. This apparatus is worked by a chain, which tightens the breaks on every one of the wheels simultaneously. The

breaks are taken off by heavy counterbalance weights, resting longitudinally over the chain in the centre of the carriage, between the front and end wheels. This apparatus is sufficiently powerful to lock every wheel, and has worked satisfactorily; for during two years, there has not been a single fracture of the chain, nor of any of the working parts. It however requires careful management, and must be applied gradually, before the train has acquired serious momentum. The friction rollers must be kept revolving, otherwise the break-van wheels wear flat places or segments in the rollers, by which their use is completely destroyed. The continuous chain is also jerked, and an undue strain thrown upon it, and upon the carriage couplings, depending in intensity upon the concavity of the segment worn on the friction rollers, and upon the tension of the chain at the time. There has been much difficulty in getting men to work this break satisfactorily; and great difference has been found in the length of time a set of friction rollers would last, depending altogether upon the care with which they are applied. One Guard has worked a set of friction rollers for fully nine months without wearing them unevenly; while several other Guards have destroyed a set in one week, and in some instances in a single trip. To prevent the wearing of these cast-iron rollers, a wrought-iron strap, or tyre, about ¾ inch thick, has been placed on their circumference, and this has been found to decrease the wear and to answer well. In future, it is proposed to make these tyres of 1¼ inch Bessemer steel. The break-van of every passenger train is now provided with sand-boxes leading to the rails; as formerly, the dew on the rails wetted the wheels of the break-van, and prevented the friction rollers of the apparatus from revolving; whereas, as soon as sand was applied, the wheels became dry, and the friction rollers acted efficiently. The cost in London of the continuous break for four carriages, and the van, was £85 per set, to which must be added freight, insurance, &c., so that the cost in place in Mauritius may be taken at £91 per set.

Every train of four or five carriages has two guards, one to work the continuous break, the other to use the separate break if necessary, attached to the end carriage, or that which was not connected with the continuous break. In general, one additional breaksman is sent for every two carriages, beyond the four which are worked by the continuous chain. During the year 1867, the 7·30 A.M. up train from Mahebourg was much overcrowded, and frequently descended the inclines with eight or

nine carriages attached; but, for the sake of giving more accommodation and greater safety, another train has now been added, so that the ordinary trains at present vary from four to six carriages.

The heaviest passenger train from Mahebourg to Port Louis consisted of fourteen carriages and two break-vans, and conveyed five hundred and thirteen troops. This was on the 14th of November, 1868, and it was kept perfectly under control, when descending the inclines, by the continuous break on four carriages, and by five additional breaksmen, the speed from Curepipe to Port Louis being steadily maintained at 20 miles per hour.

Engines attached to trains have occasionally got off the line at the points, without doing any damage, through the carelessness of the pointsman; but, with this exception, since the opening of the line, in October, 1865, there has been no accident to any passenger or goods train, nor to any passenger. There are but four instances of passenger trains getting for a time beyond control:—First, one morning when the rails were wet, a train, consisting of four carriages and the break-van, descended from Curepipe to Phœnix, a distance of $3\frac{3}{4}$ miles, in five minutes, or at a speed of 45 miles per hour. This is the highest speed on record, and it occurred before the sand-boxes were put on the break-vans. Secondly, in a similar way, another train attained a speed of 32 miles per hour. Thirdly, a train overran the Petite Rivière Station for a considerable distance, chiefly from the want of sufficient care on the part of the engine-driver and guards. Lastly, a train once attained an excessive speed in descending from Curepipe to Cluny, through the dropping off of the nut of the eye-bolt which passes through the axle on which the continuous chain of the break apparatus is wound. The last is the only instance of any casualty having yet occurred with the gearing of the continuous break, and was moreover an accident not attributable to the system.

The speed, in descending the inclines, is limited theoretically to 18 miles per hour; practically it rarely exceeds 25 miles, and the breaks on the carriages are generally sufficient to control the train, without the necessity of applying the breaks on the engine. It was at first customary to use the engine break; but the iron tyres being then found to heat, so that they would soon become loose, the practice was discontinued, and the engine break is now only applied on emergencies. The present tyres of all the locomotives are manufactured from Bessemer or Krupp's steel.

The goods trains in descending the inclines, as a rule, consist of eight

loaded wagons with the lighter locomotive, though ten have been occasionally taken, and as many as twenty empties. There have been instances in which fourteen loaded or twenty-four empty wagons have descended, but only on emergencies and under very favourable conditions. With the 48 ton locomotives, the usual number of wagons in descending the inclines is from ten to twelve and sometimes fifteen loaded, or about twenty-four empty; and, in these cases also, the breaks on the wagons control the trains, so that it is rarely necessary to apply the break of the engine.

The break power attached to the ordinary goods train is as follows:—First, two ordinary break-vans or one break-van and one goods wagon, fitted with the ordinary screw break. Secondly, every goods wagon has the usual break handle working two blocks on the wheels; and to the end of this handle, a weight, averaging 35 lbs., is attached to every wagon, exerting (including the leverage) a pressure of 90 lbs. on the break blocks.

With every train, both passenger and goods, there are at least two guards. The head guard always works the principal break-van, and the under guard works either the second break-van or a screw break-wagon, one of which invariably accompanies each goods train. In addition, a man specially employed in tightening up the break blocks before descending on either side of Curepipe (or at any other station where it may be required) accompanies each train, both passenger and goods, and works the separate break of any additional carriage, or the second screw break-wagon if there should be two of them on the train in question. The head guard of each goods train always carries in his break-van twelve of the weights before mentioned, one to be attached to every wagon, and he takes them off as the wagons are left at the stations, in order that he may always have these weights with him. Ten spare weights are also invariably kept at Curepipe for use in case of emergency. To expedite the sugar traffic in the crop season, it is found necessary to carry three or four goods wagons with most of the passenger trains, the carriages of which are worked with the continuous break; but in this case, also, a weight is attached to every goods wagon, and wagons are always placed in front of the carriages. The only instance on record of a goods train getting for a time beyond control occurred on 10th September, 1867. At Curepipe six loaded wagons were attached to a 37 ton engine. The breaks of all the wagons were then tightened up as usual, and the ordinary weights

applied, but control of the train was lost between Curepipe and Phœnix, though, on reversing the engine, the train was stopped at the latter station. Two more loaded wagons were then added, and two more at Quatre Bornes Station, making ten wagons and the van, or 110 tons in all, and after leaving Rose Hill the speed again became excessive, and it was not until the engine had been reversed, that control of the train was re-obtained.

The idea of placing Safety Sidings at the foot of the steepest inclines, near Petite Rivière and Vacoa, into which could be turned trains which may get beyond control, has long been in contemplation, but the ground is by no means favourable for the purpose, and from the difficulty of working them efficiently, it is feared that they may become a source of danger rather than of safety.

The Electric Telegraph, double needle system, is in use on this railway, and the trains are regularly signalled by it, but the telegraph lads have not yet had sufficient experience to be thoroughly reliable, and as notice to the switchman at these points must be sent by telegraph, it would require (although a simple system of signals could be adopted) a class of men very difficult to find in Mauritius.

The following rules are in force respecting vehicles which may get away from a station, or may break loose from a tr[illegible] Station ough the snapping of the couplings when ascending an incline. [illegible] at care o[illegible]

First. That on a vehicle passing any sta[illegible] station-mast[illegible] an exc[illegible] is to telegraph immediately to the nearest statio[illegible] the vehicle is proceeding, stating whether there be human l[illegible] the vehicle or not. In the latter case the wording for simplicity [illegible] ows :—

Runaway { vehicle or train } upse[illegible]

Secondly. The station-master receiving this [illegible] is then to take immediate steps to throw the runaway off the line, [illegible]ng the nearest [illegible] on switch-points half open, or by the most available mea[illegible] [illegible]t the

Thirdly. If there be human life in the vehicle or tr[illegible] if the [illegible] [illegible]rst station-master be not certain that there are no human be[illegible] it [illegible] he is to telegraph to the nearest station as follows :— [illegible]

Runaway { vehicle or train } life.

Fourthly. In this case the instructions to throw the vehicle or train

off do not apply, but it is left to the station-master receiving the latter telegram, to act to the best of his judgment under existing circumstances, the first consideration being the preservation of human life.

The following Mauritian woods have been tried for break-blocks: Tatamaca, Calophane, Bois de Natte, and Bois de Pomme; of these Calophane has been found to answer the best. The average duration and cost of a set of break-blocks are as follows:—

| | Duration. | Cost per set. |
|---|---|---|
| Continuous break-blocks, four on each carriage, . . | 21 days . | 9s. |
| Ordinary break-van, with four blocks, . . . . . . . | 30 „ . | 7s. |
| Ordinary goods wagon, with two blocks, . . . . . . | 26 „ . | 3s. 6d. |

All these break-blocks have three holes, each $\frac{3}{4}$ inch in diameter, drilled into the face, for a depth of about 3 inches, and these holes are filled with lead for the sake of increasing the grip upon the tyre, and of preventing the block from firing.

Owing to the short length of flat gradients upon which the stations are placed, the working of the sidings is rendered very inconvenient. So much is this the case at Beau Bassin, that trains are never allowed to pass there, from the fear of a collision, if the train in descending from Rose Hill should get beyond control. Union Vale Station is also objectionable; and at all the stations, great care has to be exercised with wagons left in the sidings. To prevent wagons from breaking loose, a heavy stop-block, say 12 inches square, passes over both rails of each goods siding previous to its junction with the main line, and these blocks are always kept strictly locked, except when the goods trains are actually passing through them. The rules especially provide, that no wagon is to be moved by hand, either on the main line, or on the through siding, nor beyond the limits of the stop-block, and that no wagon shall be uncoupled from the engine until brought to a dead stand within the stop-blocks. This latter rule though somewhat relaxed in practice, has been fairly maintained, and only one instance of a wagon running away has yet occurred, and that through the carelessness of the station-master. In general, a man is placed to shut the stop-block the moment the wagons have passed through it. As a principle, it is held essential to reduce the number of points on the main line to a minimum, and therefore the goods sidings always branch off from the through sidings, and not from the main line itself.

*Traffic returns.*—It is impossible to give a fair statement of the traffic returns, on account of the exceptional circumstances under which the line is still working. For the first year's traffic, the passenger receipts for 1866 may be taken as a fair commencement, and they are now steadily, though not rapidly, increasing, notwithstanding that the short sugar crops for four years, 1861-67, had seriously affected the prosperity of the colony, and have naturally diminished the amount of passengers, as well as of goods, which would otherwise have been carried. The unusual drought which since 1862 has prevailed in Mauritius has caused a most serious diminution of the sugar crop: the crop for the season 1862-63, which reached 158,161 tons, having fallen off to 108,237 tons in the season 1866-67. Owing also to the want of sufficient locomotives, and to the unusual wear of the iron tyres of the driving-wheels, which, through a defect in the manufacture, required to be two or three times "turned up" after running on the average only 4,128 miles between each turning, the amount of goods conveyed during 1866 affords no criterion of the capabilities of the line. From February to July inclusive of the year 1867, the colony suffered from an epidemic fever, unparalleled in violence, the number of deaths having been 34,233 out of a population of 341,165, or more than 10 per cent. During the month of April, out of a population of 75,000, the mortality of Port Louis averaged 207 per day, a rate sufficient to have exhausted the population of the town in one year, and, including the mortality in other districts, to have swept off the entire population of the colony in two years and nine months. Many whole families were carried off leaving none remaining, business of every description was almost wholly suspended, and the revenue of the colony decreased by one half, the loss being about £1,000 per day.

Although it is but natural that the passenger traffic during the first six months of the year 1867 should have considerably decreased, as compared with the corresponding period of 1866, still the traffic for the whole of 1867 will compare favorably with that of 1866.

The following are the figures in each case:—

| | 1866. | 1867. | Increase. | Decrease. |
|---|---|---|---|---|
| Number of passengers, . . . . . . . . | 519,524 | 430,052 | .. | 89,472 |
| | £ | £ | £ | £ |
| Passenger Receipts, . . . . . . . . . . | 31,979 | 30,225 | .. | 1,754 |

| | 1866. | 1867. | Increase. | Decrease. |
|---|---|---|---|---|
| | £ | £ | £ | £ |
| Parcel Receipts, | 546 | 797 | 251 | .. |
| Telegraph Receipts, | .. | 43 | 43 | .. |
| Miscellaneous Receipts, | 11 | 102 | 91 | .. |
| Suspense Traffic, | 173 | .. | .. | 173 |
| | tons. | tons. | tons. | tons. |
| Goods, Number of Tons, | 18,047 | 31,998 | 13,941 | .. |
| | £ | £ | £ | £ |
| Goods Receipts, | 7,675 | 14,272 | 6,597 | .. |
| Total Revenue, | 40,384 | 45,439 | 5,055 | .. |
| Total Expenses, | 25,319 | 30,856 | 5,537 | .. |
| Profit of the Year, | 15,065 | 14,583 | .. | 482 |

The passenger rates are as follows :—

| | |
|---|---|
| First class | 4*d.* per mile. |
| Second „ | 2½*d.* „ |
| Third „ | 1*d.* „ |

Return tickets for the first and second class being 50 per cent. more than the fare for a single journey.

The rates for goods vary according to the usual classification, but for sugar, provisions, and manure, which form fully three-fourths of the whole tonnage, the charges, including terminals, are as follows:—Sugar and provisions from Mahebourg to Port Louis, 35 miles, or *vice versâ*, 10*s.* per ton, equal to 3·42*d.* per ton per mile. Sugar and provisions from Rose Belle to Port Louis, 24 miles, or *vice versâ*, 9*s.* 2*d.* per ton, equal to 2·60*d.* per ton per mile. The rates for these articles from stations intermediate between Rose Belle and Port Louis are about 5½*d.* per ton per mile. The charge for manure from Port Louis to Mahebourg is 7*s.* 6*d.* per ton, equal to 2·60*d.* per ton per mile.

The short distance of this railway (single line) tells of course greatly against the receipts, and, from the severe character of the gradients, it has never been deemed prudent to run trains by night.

*Cost per engine mile.*—During the year 1866, the locomotive cost per engine mile run was unexceptionally high. The price of fuel then averaged 41*s.* 5*d.* per ton, or, including delivery and stacking, 44*s.* 5*d.* Again, the iron tyres of the side-tank engines wore so rapidly, and the number of locomotives for the work was so small, that a considerable additional expense was incurred beyond their fair repairs. These disadvantages have now been remedied, and the locomotive cost per engine mile run is at present as follows :—

| | *d.* | *d.* |
|---|---|---|
| Cost of fuel per mile | 10 90 | |
| „ oil, tallow and waste, | 1 20 | 12·10 |

| | d. | d. |
|---|---|---|
| Cost of materials for repairs of engines,.. .. .. | 2 08 | |
| „ materials for repairs of carriages and wagons, | 1·84 | 3·92 |
| Salaries of superintendent, drivers, firemen, and cleaners, | | 6·19 |
| „ mechanics repairing engines,.. .. .. | 2·57 | |
| „ „ „ carriages and wagons, | 1·40 | 3·97 |
| Total per mile run, .. .. .. .. | | 26·18 |
| The consumption of fuel per mile run is, .. .. .. | | 49 7 lbs. |

*Labour.*—As these expenses are still double the cost at home, it is necessary to make a few remarks respecting the value of the skilled labour and the supplies obtained from England. The engine-drivers, carriage foremen, and platelayers were all engaged in England to serve in Mauritius for three years certain, it being optional with the Government to extend the agreement to five years, on giving notice to that effect six months prior to the expiration of the former period. The salary of the engine-drivers is for the first year £192, for the second year £216, and for the third year £240. Sunday work is paid for in addition at the ordinary rate, and the drivers have also the use of free quarters. The salary of the carriage foreman was £300 per annum, but this office is now filled satisfactorily by a Mauritian at about £150 per annum. The platelayers receive £150 per annum, with a bonus of £25 per annum, on receiving a certificate of good conduct; and they also enjoy free quarters, though this advantage is neither in their agreements nor in those of the drivers. The Government provide free passage for all these men from England to Mauritius and back (except in case of misconduct), the expenses thus incurred being about £130 per man. As yet no attempt has been made to train engine-drivers in Mauritius, it being difficult to find men having sufficient nerve and intelligence, although it is hoped that some of the lads now training in the shops may eventually become drivers.

All other skilled labour is found in Mauritius. The Creole carpenters, masons, blacksmiths, and fitters are fair workmen, though slow and not over industrious. Comparing their wages and amount of work done with the value of similar labour in England, the cost in Mauritius is from 10 to 15 per cent. more than at home.

The maintenance of the permanent way is under the charge of English platelayers, whose districts average 12 miles each, and who superintend

the Coolie labour. Every day, wet or dry, Sunday inclusive, each district is minutely inspected on foot by a reliable Indian, who carries a keying hammer; and this man is frequently accompanied by another Indian carrying a spanner. In addition to the ordinary platelayers' rules, special instructions have been given respecting repairs on the Midland line. After a little practice, the Indians work well at packing the sleepers, and keep the road in very good condition. The number of Coolies required averages four per mile, and their usual wages are £10 per annum, plus rations, the ordinary value of which is £5 10*s.* per annum. The cost of all salaries and labour employed in maintaining the road, but without any renewals worth mentioning, none of which have as yet been required, has been as follows:—

| | Per Mile per Annum. | | |
|---|---|---|---|
| | £. | *s.* | *d.* |
| Salaries of Engineer, Inspector, and Office expenses, | 20 | 0 | 0 |
| Wages of platelayer, .. .. .. .. .. | 14 | 12 | 0 |
| Coolies, four, at £15 10*s.* each, .. .. .. | 62 | 0 | 0 |
| Tools about, .. .. .. .. .. .. | 3 | 8 | 0 |
| | £100 | 0 | 0 |

During the years 1864 and 1865, contracts were made in England for the supply of fully 6,000 tons of Newcastle and Welsh coal, to be delivered in Mauritius at prices ranging from 34*s.* to 49*s.* 10*d.* per ton, and in consequence of freight being then unusually high, this coal averaged 41*s.* 5*d.* per ton. Latterly, Australian coal, from Newcastle, Wallsend, and Waratath mines, Sydney, has been found very satisfactory, and equal to any English coal imported; so much so that it will be chiefly used in future. The cost of this coal, delivered in Port Louis harbour, is usually 32*s.* to 40*s.* per ton. The cocoa-nut oil manufactured in the colony, and used for the locomotives, and for all machinery, answers well. The ordinary price is 3*s.* 4*d.* per gallon. Tallow is obtained from Australia at 7*d.* per lb., and carriage grease is made by the Department at a cost of about 70*s.* per cwt. With these exceptions, the usual stores are chiefly obtained from England, the price of ironmongery and of most articles being fully double their cost at home, and often more. The cost of freight, packing, and insurance on articles received from England, adds nearly 14 per cent. to their original value when delivered in the colony.

Considering, therefore, the high price paid for skilled labour and for fuel, the agricultural character of the district through which the railway

passes, the severity of the gradients, the want of anything that can be called a town save at Port Louis, the lack of minerals or manufactures to transport, the peculiar nature of the sugar traffic—requiring a large amount of rolling stock for three months in the year, whereas for the remaining nine months less than half that quantity would suffice—under all these unusual circumstances it is not surprising that the working expenses of the Midland line should, in 1866, have been 62½ per cent. of the receipts, or 5*s*. 5*d*. per train mile.

Fortunately, some of these exceptional circumstances have now ceased to exist. The arrival of the 48-ton engines has enabled a larger amount of sugar to be carried; and when the goods traffic becomes further developed, a considerable decrease in the percentage of working expenses to the receipts will naturally ensue, accompanied also, it is hoped, by a reduction in the cost per train mile.

It may be, of course, sometimes impossible to construct a railway with easier gradients than those on the Midland line, but the difficulty of working these inclines in wet weather has been so great, the load haul so small, and the speed so low, that the Author thinks the severity of any gradient for a long rise should never exceed 1 in 40; and that it will always be preferable (under the ordinary system of tractive power) to incur, within reasonable limits, any additional expense that may be requisite to bring the inclination within this ratio. It is also suggested that in laying out such inclines, whatever may be the ruling gradient (provided it be not entirely exceptional, and where additional power can be applied) that this gradient be then followed throughout the line, as far as the features of the country will permit; pieces of level being introduced between the different inclinations, as, on descending, these level portions are found of the greatest value in controlling the train. The Author believes it to be safer to work steeper gradients, provided there be pieces of level between the different inclinations, than to work a uniform gradient, extending both over the former inclines, and over the level portions, the ratio of all these inclinations being of course within reasonable limits, or say not steeper than 1 in 40.

J. R. M.

# No. CCLXIX.

## STEAM ROAD ROLLERS IN INDIA.

*Report on working of Aveling and Porter's Rollers.* By F. L. O'Callaghan, Esq., *Exec. Engineer, Kanhan Division.—Dated 9th December,* 1869.

I have the honour to report upon the Steam Road-Rollers lately received from England.

These machines were received too late in the season to be used upon the metalling operations of the Northern Road, except for a small and unimportant portion. I am, therefore, able to give an opinion only on a limited working of the rollers.

I will first detail the effects of these rollers on fresh metal as far as I have seen; second, the cost of working; and third, what I consider would be improvements in their construction when required for work in this country.

*Effect on fresh metal.*—The whole of the metalling between Kamptee and Seonee had been completed some time before the rollers were received, but as I wished to try the power of the machine on limestone metal, I had about 100 yards of this description laid down in the 44th mile. The old road was first slightly picked up, and the metal was laid on dry.

I took the roller over each portion three times. At first it seemed as if the front or steering rollers had a tendency to force the metal outwards at both sides, but this was quickly corrected by the driving rollers following; they, however, in their turn, forced some of the metal

they came over outwards on the outside of them, and that already gone over by the leading roller seemed to spring up. This effect, however, was only noticeable on *first* going over the metal; on the second occasion, the metal did not show any tendency to move laterally, having been pretty firmly packed by the first rolling, and after the third time, the metal appeared as firm as it was possible to make it by the roller.

The metal was now quite ready to receive the topping or binding coat, and as I wanted to push on towards Seonee, I left it in the hands of the contractor, who had the work on this part of the road to finish. On my return from Seonee a few days afterwards, I found this piece of road in excellent order, and far better than it would have been in the time, if only the ordinary rollers and rammers were used.

The next opportunity I had of trying the roller was in the 82nd mile, which had a fresh 4-inch coat of basalt metal laid on about a week before the arrival of the roller in Seonee; but owing to the weather being comparatively dry, the metalling had completely turned up, and was nearly as loose as when first laid.

The roller (now in charge of the driver sent from England, who had just joined) was set to work on the morning of the 26th of September, and by evening, the road was quite firm and fit for traffic, and has ever since remained so. As the topping was spread when the metal was first laid down, it caused a good deal of inconvenience when starting the Engine, as it adhered to the rollers, lifting pieces of stone along with it. The topping was almost mud, owing to a heavy fall of rain the night before, but by waiting until it had dried somewhat, this source of inconvenience was removed. The roller was not more than seven hours actually at work on this mile, owing to the above-mentioned delay, and its having to be taken over two miles from Seonee before commencing work in the morning, which occupied nearly an hour and a half.

When at work on this mile, the Chief Commissioner, who was accompanied by Mr. Noble Taylor, witnessed its performance.

For the remaining time the roller was working in this Division, it was employed in the section of 21 miles between Seonee and Chupparah.

The whole of this length was much improved by it; and on my inspection tour on the 28th of last month, I found the metal in excellent order, though in other years, it had generally given much trouble by working loose soon after the dry weather set in.

*Cost of working.*—The cost of working is more easily arrived at than the effect on new metal, and is as follows:—

| | For 1 day. RS. | A. | P. |
|---|---|---|---|
| 1 Driver, at Rs. 5 ... ... ... ... ... | 5 | 0 | 0 |
| 1 Steersman, at Rs. 3 ... ... ... ... ... | 3 | 0 | 0 |
| 2 Stokers, at As. 8 ... ... ... ... ... | 1 | 0 | 0 |
| 8 Water-carts, at As. 12 ... ... ... ... | 6 | 0 | 0 |
| 4 Fuel-carts, at As. 12 ... ... ... ... | 3 | 0 | 0 |
| 10 Coolies, at Rs. 3-3 ... ... ... ... ... | 2 | 0 | 0 |
| Oil, cotton, waste, &c., ... ... ... ... | 1 | 8 | 0 |
| | 21 | 8 | 0 |
| 60 Maunds fire-wood, at 4 maunds per rupee,... ... | 15 | 0 | 0 |
| | *36 | 8 | 0 |

These data, of course, only apply to this Division, and will vary according to the cost of fuel. To this ought also to be added a fair sum to cover repairs; Rs. 350 per annum would be a more than ample allotment, and as the working time may be assumed at 80 days in the year, (26 days a month during the rains) the amount per day for repairs

| | | | | |
|---|---|---|---|---|
| will be ... ... ... ... ... | Rs. | 3 | 8 | 0 |
| Add, as above, ... ... ... ... | ,, | *36 | 8 | 0 |
| | Total Rs., | 40 | 0 | 0 |

The allowance I make for fuel is also more than was actually expended, by about 20 per cent., but I have considered it fair to give a good margin to allow for waste and inferior fuel.

The machine rolls six feet in width at a time, and so has to travel two miles for every one mile of road gone over once (the Northern Road being metalled 12 feet wide).

The roller travels over fresh metal at the rate of about one and a quarter mile per hour, or about twelve miles per day of ten hours, and so could go over every part of a mile of metal six times; this will I think, from what has already been shown of the effects of the roller, be amply sufficient to complete that length.

* The pay of the Driver is that of the man sent out with the machines from England, and that the Steersman allows for a European also, of the rank of an Overseer.

Two of the water-carts are required to supply the engine with water, and the remaining number for watering the road.

The ten coolies are required for bringing fuel and water from the carts to the engine.

The cost of consolidation of metal by the ordinary rammers is Rs. 158 per mile, not, of course, allowing for picking up the old road, spreading the metal, or dressing off the sides, which works are common to both methods.

This shows the saving effected by the use of Steam-rollers as Rs. 158—Rs. 40 = Rs. 118 per mile, or even allowing that each mile required the roller to work on it for a day and a half, the saving would be Rs. 100 per mile, which, if the machine was kept fully at work for one season of three and a half months, or say 90 working days, would show a saving of Rs. 6,000 on 60 miles of metal consolidated, equal to three-fourths of the prime cost of the roller.

*Suggested improvements.*—These rollers, as at present constructed, are perhaps all that can be desired for the work for which they were designed at home, viz., laying down metal in streets and thoroughfares in a cold climate where space is an object, and it is indispensable to confine the width of the machine to the breadth actually covered by the rollers; but the case is different in this country, where they are required for long lines of communication.

The first addition I would recommend, and which is absolutely necessary if Europeans are required on the machine, is a good awning, extending from the centre of the turn-table frame up to the funnel. This awning should be double with at least a space of four inches between the upper and lower covering.

*Next,* the fuel-bunker is totally inadequate to the requirements of the machine; as on a long line of road, it would be extremely inconvenient to have fuel depôts at nearer distances than 10 miles apart. It is, therefore, necessary that the machine should carry or draw behind it enough fuel for one day's consumption. This might be most conveniently done by having a tender sufficiently large to carry a supply of fuel for one day's work, which the engine should be able to draw after it with its load of fuel every morning from the halting place to the mile it was to work in, and by having a bunker on the machine capable of holding a supply sufficient to run a little over two miles, then at the end of each double run it could replenish the bunker from the tender.

*Thirdly.*—The foot-plate is unnecessarily cramped, especially on the steering wheel side, and might be at least one foot wider, thus allowing the steersman a little room; an extra foot in width on the driving

side would also make it more comfortable, and allow room for a Native stoker to work on it in addition to the Engine-driver.

*Fourthly.*– As it is often required in this country to take the roller long distances to the scene of its work it would be highly desirable to have the engine geared to two different speeds, viz, one for working over metal, the same speed as the present machines travel at, and the other, a quicker one, say 5 to 6 miles an hour, for travelling to or from work. This, of course, would require a larger engine and more boiler power.

*Fifthly.*—I would strongly recommend the engine being made with two cylinders, instead of one, and the fly-wheel being greatly reduced in weight, or altogether done away with.

*Sixthly.*—The engines might be made of a somewhat larger horse-power than at present, to enable them to lift the roller out should it sink in a freshly made road.

*Seventhly.*—The ash-pan, as at present constructed, is inconvenient when wood is used for fuel, being difficult to get at to clean.

These are the only alterations that at present suggest themselves to me, though a larger experience in the use of the rollers may bring out other little points that might be altered with advantage.

In conclusion, I would express regret that, for reasons explained I am unable to forward a more detailed and satisfactory report on the working of these machines, though, as far as I have yet seen, they fully come up, in my opinion, to the expectation formed of them.

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*Memo. by the Chief Engineer.*

The report Mr. O'Callaghan has submitted, as he remarks, is not very satisfactory, for the rollers were received so late in the year, that all our metalling operations were completed at the date the machines arrived at Nagpoor. The actual work done by the one roller worked was so limited, that it may be termed experimental, and was more of a "trial trip" nature than anything else; this is unfortunate, but was, for reasons given, entirely unavoidable.

I saw the work done by the roller, as above described by Mr. O'Callaghan.

I considered the metal was sufficiently consolidated. The topping

should not be put on until the metal has been rolled by the machine three or four times. I would prefer topping after the third rolling, and then giving a fourth to consolidate the moorum or gravel surface dressing. I believe this will be sufficient for monsoon work. The dressing should be rolled dry or nearly so, otherwise the rollers lick up the topping and pieces of stone with it, and so break the upper crust of the metal.

*The cost of working and of consolidating the metal.*—This is very important; if the rollers do not ensure a saving both in time and money over the common method of consolidating metal, the machines are failures.

In my letter of September 22nd, 1868, written when I was Superintending Engineer, Nagpoor Circle, I estimated the cost of working the steam-roller at Rs.* $\frac{1000}{26}$ = Rs. 38-8-0 per day. Actual practice, in October 1869, gives the cost per day to be Rs. 40, including however an allowance for repairs to the roller which I did not allow for.

The work done by the roller, so far as our experience tell us, is 12 miles of fresh metal travelled over in 10 hours, one mile of metal consolidated in one day of 10 working hours, the speed over fresh metal being about 1¼ miles per hour. The metal is 12 feet in width. The rollers cover one-half, or a strip 6 feet in breadth, and each is supposed to be rolled six times. The cost is therefore Rs. 40 per mile under this data. I anticipate that during rainy weather, and when the metal is wet, three rollings will suffice, with a fourth as a finishing one after the topping is spread.

This would reduce the actual and working cost per mile to Rs. 26 or Rs. 27, but more practice is required before this estimate can be relied upon.

My former letter showed approximately what loss has been sustained from the rollers arriving too late this year to take part in metal consolidation, and without taking the whole gain in support of this statement, I consider that with perfect safety Mr. O'Callaghan's data can be adopted. This is, that Rs. 6,000 would be saved upon 60 miles of metal consolidation in one season, and this amount would have been the *least* sum gained had the roller been in the Kanhan Division in June last. It will be observed, moreover, that this saving is ¾ths the cost of the machine.

I must explain, however, that the Northern Road is peculiarly favorable for working steam-rollers. It is bridged for about 145 miles; or

* No. of working days in a month.

from the Kanhan to the Nerbudda River; again it had an old, and a somewhat solid, crust of metal, before our late re-coating commenced.

It would be inconvenient and a source of delay if the roller was brought for work to a road whose intersecting rivers and nullahs were unbridged, and the more numerous such gaps, the more the delay and trouble. The roller would have to be taken to pieces at almost all of these breaks, unless expensive temporary tracks were got up; and if the rivers held deep water, shipping and unshipping the machine, even when in pieces. is a slow process, requiring careful supervision.

Further, the rollers are not very suitable for consolidating first coats of metal. If this was attempted in the monsoon, at any rate in this part of India, they would sink into the fresh banks of earth, and simply stick then and there; on old embankments, consolidated some time, this evil would be felt less, but even on these, unless in comparatively dry weather, delays and sinkings would be frequent.

Once a first crust of metal is laid, then for all successive layers it can be used, and I consider with considerable economy, much saving in time, and good work as the result.

*Suggested improvements.*—I coincide with the proposals made by the Executive Engineer in regard to the improvements that are required for the employment of the Machine in India.

T. W. A.

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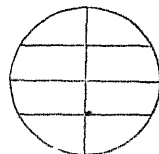
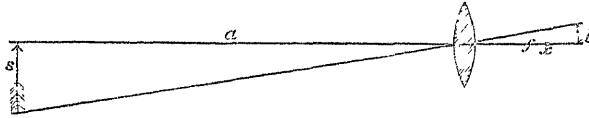
# No. CCLXX.

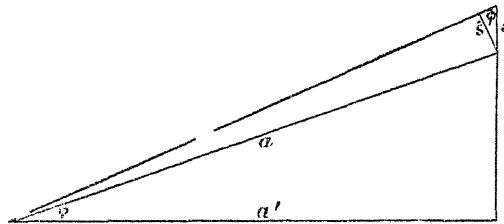
## TELESCOPIC MEASUREMENT IN SURVEYING.

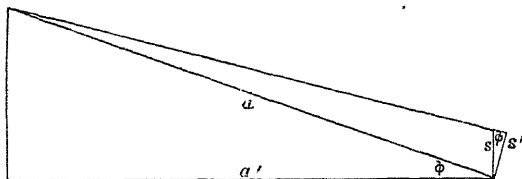
*By* BENJAMIN SMITH LYMAN, *Mining Engineer*, 135 *South Fifth Street, Philadelphia.*

*Read before the Franklin Institute, at the Stated Meeting, March* 18*th*, 1868.

FOR measuring distances with the telescope, in surveying, the telescope has two or more horizontal cross-hairs besides the ordinary vertical one. In sighting at an upright rod, these horizontal cross-hairs cut off a portion of the rod that is larger or smaller according to the distance of the rod; five times, as much, for example, for a distance of a thousand feet, as for one of two hundred feet. A rod graduated to indicate distances in this way, with the help of the telescope, is called a *stadia* by the French, and has been in use some fifty years. In the United States Coast Survey such a rod is called a *telemeter*. The object of this paper is to show that such telescopic measurements in their simplest form are more exact than is perhaps commonly supposed, even by professional surveyors; as well as to point out some improvements in the details of the apparatus that add very much to its convenience.

De Sénarmont, nineteen years ago, in the *Annales des Mines* (Fourth Series, vol. xvi.), in a notice of some improved apparatus for telescopic measuring, by Mr. Porro, a Piedmontese, speaks of the stadia as having been used hitherto for rapid and approximate surveys; and gives briefly the theory of its use. If the size of the object seen through the telescope be called $s$; the distance from the object to the centre of the objective $a$; the size of the conjugate image of the object, equal to the distance apart

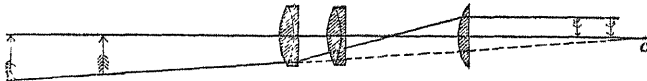
of the two horizontal cross hairs, $i$; the distance of this image from the centre of the objective $x$; and the focal length of the objective $f$: then,

$\frac{a}{x} = \frac{s}{i}$. But the general formula of foci of lenses gives $\frac{a}{x} + 1 = \frac{a}{f}$. Therefore, $a - f = \frac{f}{i} s$; or $a = \frac{f}{i} s + f$. Practically the distance $a$ has commonly been reckoned so large that the small distance $f$ was neglected, and the formula became $a = \frac{f}{i} s$; in which $\frac{f}{i}$ is a numerical co-efficient peculiar to the instrument, and determined by observation once for all. The distances, in that case, are reckoned proportional to the space cut off on the rod, counting from the centre of the instrument, whereas they ought strictly to be counted from a point as far in front of the objective glass as the focal length of that lens.

In case the telescope in measuring is not level, it is necessary to make besides a double correction; because, in the first place, the space cut off on the vertical rod is greater than if the telescope was sighted level; and, in the next place, the corrected distance of the rod in the slanting direction must be corrected again to give the distance reduced to a level. For

if $s$ be the space cut off on the rod viewed slantingly, and $s'$ the corresponding space when the rod is held square with the line of sight; if $a$ be the distance of the rod from the telescope in the slanting direction, and $a'$ the correct horizontal distance; and $\phi$ the angle of the slant with the horizon: then $a' = a \cos \phi$; $s' = s \cos \phi$; $a = n s'$, where $n$ is the

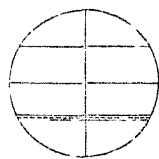
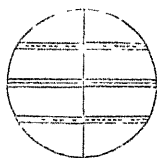
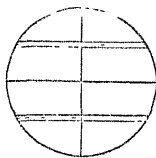
numerical co-efficient $\frac{f}{i}$ peculiar to the instrument; and $a' = a \cos \phi = n\, s' \cos \phi = n\, s \cos^2 \phi$. It is necessary, then, to multiply the distance

indicated by the rod by the square of the cosine of the angle of the sight with the horizon. If, however, account be taken of the necessity, for exactness, of counting the distance $a$ from a point as far in front of the object glass as the focal length ($f$) of that lens; and also account of the distance of that lens in front of the axis of the instrument, say $d$; then, $a' = (a + f + d) \cos \phi = n\, s \cos^2 \phi + (f + d) \cos \phi$. But $(f + d)$ is so small a distance, that, with the angles common in practice, it differs but a trifle from $(f + d) \cos \phi$, and may be reckoned as the same thing; so that, then, $a' = n\, s \cos^2 \phi + (f + d)$. The quantity $(f + d)$, then, is a small constant, easily determined for each instrument, say one foot or two, that must be added to each level measurement, and to each corrected slanting measurement. Sometimes, when the telescope is not level, the rod is bent over so as to be square with it; but this is less convenient than the way of correcting just described; for the correction for the slope of the ground has to be made at any rate, and it is extremely easy to make the other at the same time.

De Sénarmont remarks that experience shows it is possible to subdivide, by guess to a tenth, a space that subtends an angle of about sixteen minutes. If, then, the rod, when magnified by the telescope, subtends an angle of about ten degrees, its length could be marked off in forty divisions, and each of them be subdivided by the eye within a tenth. If, for example, the telescope magnified ten or twelve times, like the ordinary ones on transits, for a range of say 660 feet (ten chains or a furlong), then the rod might be something over thirteen feet long, and be marked with divisions a third of a foot long, and then could be subdivided by the eye within a thirtieth of a foot. This limit of exactness would correspond to a foot and two-thirds of distance on the ground, or

$\frac{1}{400}$ of the furlong. But if the telescope magnified twenty times, like the telescopes of levels, the divisions on the same rod could be twice as small, so that the limit of error in the reading of the rod would be twice as small also: and the error in the distance on the ground, therefore, would be not more than five-sixths of a foot, or $\frac{1}{500}$ of the whole distance. This, however, is about the greatest exactness that can be obtained in this way with ordinary glasses; since, in this case, the magnified rod extends about ten degrees in either direction from the focal axis, and more than that, the eye-glass cannot embrace without aberrations that are quite too great; so that, if the power of the telescope be increased, the length of the rod and of its divisions must be diminished in proportion.

Mr. Porro's improvements, then, aim at an increase of the field, and at the same time of the power; and, besides, the distances are made to count from the axis of the instrument. This last change is effected by placing, between the focus of the objective and the cross-hairs, an additional lens whose focus is at the same point as the focus of the objective. The rays, then, after passing the added lens are parallel, and all objects that subtend the same angle from a certain point ($c$) behind the objective (a point which he calls the centre of "anallatisme," that is, of unchangeableness, and whose position is determined by the refraction and distances of the lenses) would have images of the same size, and the size of the objects would be proportional to their distance from that centre. The cross-hairs would then cut off a space on the rod proportional to the distance of the rod from the centre of unchangeableness, and this centre may be placed at the axis of the instrument; so that the distances found by reading the rod would be counted immediately from that axis, and if they were not level would be corrected, to get the level distance, simply by multiplying by the cosine square of the angle above or below level.

Then, in order to increase the available extent of the field, Mr. Porro used three eye-glasses, which observed the upper, middle and lower parts of the image; so that the cross-hairs could be put farther apart; and, by having an eye-glass opposite each one, no error would come from the spherical aberration. But, in order to have a sharp and bright image for

these eye-glasses to observe, and yet not to need a large objective (which would require a focal length at least twelve times as long as the diameter of the lens to avoid excessive spherical aberration), he used two separate achromatic objectives placed one behind the other; that is, a compound lens, such as had long been used for achromatic microscopes and for cameras. By these means, he made telescopes of two inches and a third across, and only about fifteen inches in focal length, with a magnifying power of sixty or eighty times; and with the triple eye-piece they enabled him to read distances within at least $\frac{1}{2000}$, and so reduced the uncertainty to less than a third of a foot in 660 feet.

More than that, instead of using simply two horizontal cross-hairs, one above and one below, with or without the middle cross-hair, he always replaced the lower cross-hair by two, at one-tenth the distance from each other that the replaced hair would have been from the upper one, making three cross-hairs, besides the middle one. Sometimes also he replaced the upper in like manner by two, making five, counting the middle one; and sometimes he placed two more just above and below the middle, making seven cross-hairs in all. These additional cross-hairs serve to show that there has been no material error in the reading, and that the divisions of the rod have been correctly subdivided by the eye, and that the sighting is correct when certain divisions are not distinctly visible owing to obstructions. He obtained in this way, with a magnifying power of sixty or eighty times, and with five cross-hairs, and with the divisions of the rod $\frac{1}{100}$ of a foot (four centimetres) long, an exactness within less than $\frac{1}{2000}$ up to a distance of a furlong, between a furlong and a quarter of a mile the middle cross-hair and two outermost ones, gave an exactness of a good deal less than $\frac{1}{1000}$; and between a quarter of a mile and half a mile, one of the outer pairs of cross-hairs, gave an exactness within $\frac{1}{400}$.

De Sénarmont remarks that such a telescope may be advantageously adapted to geodetical, levelling, topographical or land-surveying instruments; but that, applied to the ordinary compass, to the alidade of the plane table, or to the graphomètre, it would give, even with a reduced

magnifying power, a greater exactness than could be obtained with these instruments for the other elements of a topographical projection; and so some of its advantages would be wasted. He admits, also, that the instrument requires extremely nice workmanship, such as few instrument-makers are capable of; and, although it is possible to test the correctness of the different parts, there appears to be no way of adjusting the position of the cross-hairs without removing them from the telescope.

If, however, the number of horizontal cross-hairs be restricted to three, one above and one below the middle one, they can all easily be made adjustable by screws on the outside of the telescope, if the upper and lower hair be placed a very slight distance before or behind the vertical hair, a distance that can give rise to no inconvenience. Observations with the two upper and two lower of the three cross-hairs, (that is, with all three at once,) check each other, and if too little of the rod be visible for that, then two successive observations on different parts of the rod, with either one or both pairs, serve the same purpose. In these ways, the lack of Porro's additional cross-hairs is very conveniently supplied, except in the sights that are more than a quarter of a mile long. These extremely rare sights, where even his apparatus claims only the indifferent exactness of $\frac{1}{400}$, it is necessary to give up, and make instead two shorter sights with more exact results.

A convenient way of marking the rod with very small divisions removes the fatiguing necessity of subdividing the divisions by the eye to a tenth, and enables the use of a much weaker telescope. According to Plateau, a red disk, lighted by sunlight merely reflected by the clouds, can be seen distinctly at a distance equal to 6000 times its diameter; according to Müller, at a still greater distance, especially with a favorable background; but with a telescope magnifying twenty times, this distance of distinct visibility becomes 120,000 times the diameter of the disk. It has already been seen that, with a simple telescope of that power, the rod can be at most something over thirteen feet long for a range of a furlong; that is, the length of the rod may be one-fiftieth of the length of range. The smallest visible mark on this rod at the distance of a furlong would be not more than $\frac{1}{120000}$ of 660 feet, say $\frac{1}{182}$ of a foot long. A cross-hair, wherever it should cut a rod divided throughout with such marks, would be within one-half the length of a mark from the centre of one of them, or within $\frac{1}{364}$ of a foot of the reading; and this would correspond

to a distance of $\frac{50}{364}$ (less than a seventh) of a foot on the ground. This, then, would be the exactness with such a telescope and such a rod, $\frac{50}{364}$ of a foot in 660 feet, or $\frac{1}{4800}$; and, for distances between a furlong and a quarter of a mile, the exactness would be within $\frac{1}{2400}$. That is more than twice as exact as Porro's large and complicated instrument with his rod less finely divided; and yet requires no larger field than can be got with a common telescope that magnifies twenty times and has but a single eye piece. A magnifying power of ten times with a rod of the same length would give one-half the degree of exactness at those distances; and the marks on the rod must be twice as large, say, $\frac{1}{100}$ of a foot long. At a distance less than a furlong, a smaller space on the rod could be distinguished, but it would be the same fraction of the distance measured, so that the exactness would be no greater.

Such small divisions are readily marked on the rod, and made easily legible simply by dividing the feet into tenths, and marking each tenth of a foot with an angular figure, whose angles indicate each a division of one-hundredth of a foot. The rod marked in this way can be used for levelling as well as measuring; and the cross-hairs can be adjusted so that one foot on the rod between the middle and upper or lower cross-hair corresponds to a hundred feet, and the reading gives the distance directly in feet. So adjusted, a telescope that magnifies twenty times uses in measuring just the whole of its available field; but a telescope that magnifies ten times uses only half of it, and is therefore far within the limits set by the spherical aberration of the outer part of the field.

The correction done away with, by using the additional lens and reducing the centre of unchangableness to the axis of the instrument, is otherwise made simply, as already shown, by merely adding to every distance, as read from the rod, a constant (say, one foot) equal to the focal length of the object glass added to the distance of that glass in front of the axis of the instrument, that the use of those complications seems, on the whole, to have no advantage.

Instead of reading the distance directly on the rod by the telescope, a movable target may be used with a vernier. One cross-hair is sighted at the zero point on the rod, or at a fixed target, and the movable target is moved to correspond with another cross-hair, and the space cut off in this way on the rod is read by the rodman; and if a vernier be used,

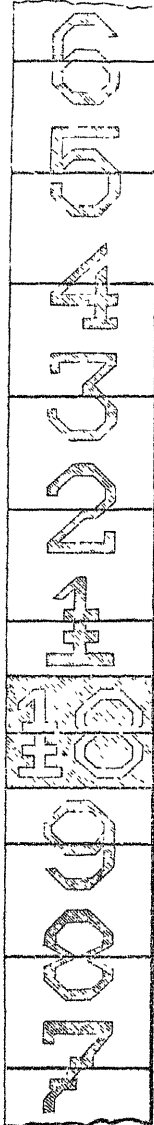
can easily be read to a thousandth of a foot, if desired. Such a rod was used in 1862, in a topographical survey in Schuylkill County, with a measuring telescope that magnified about ten times attached to a light compass. There were three horizontal cross-hairs, not adjustable, but fixed, by chance, at such a distance apart that two inches on the rod between the middle cross-hair and either one of the others corresponded to ten feet of distance on the ground.

The exactness of this measurement was satisfactory, but the moving of the movable target was so tedious, that the following year a rod was made for similar topographical use, so marked that the distances might be read directly with the same telescope. The numbers of every other division on the rod were indicated by diamond-shaped spots, two-fifths of the division in diameter, and placed on either side of a dividing line, with one point at one-fifth of the division from the line, and the opposite point at twice that distance from the next line; so that the whole of each division was easily divided by the eye into ten parts, by halving the side of a spot, or halving or quartering the space between the spot and a dividing line. The cross-hairs were put nearer together, too, so as to bring them further from the outer edge of the field. It was wished to have them just half as far apart as before; but they proved to be so far apart, that $\frac{36}{35}$ of an inch on the rod corresponded to ten feet of distance, and the rod was divided accordingly. This telescope and rod were used very successfully through the summer and autumn of 1863. The first part of the season, the levels were taken by means of angles on a vertical circle, as they had been the year before; but after that, to avoid the uncertainties and excessive office work of that method, an ordinary level-rod was carried, besides the one for measuring, and the level was taken by a separate observation for each station, with the help of a spirit-level attached to the telescope of the compass. The running, in such a case, is done with front and back sights, like levelling, with one rod; and, as the sights are level, no correction is needed for slope. The exactness of these methods, even with so slight an instrument as the compass was, and their thorough satisfactoriness in that respect for geological purposes, are illustrated by the fact that a shaft was sunk, in 1866, in Cape Breton, at a point where it was calculated by a map constructed, in 1863, from materials obtained in this way, that the bottom of a certain coal-bed, dipping about one in ten, would be 180 feet deep, a point about three-quarters of a mile distant

from the nearest exposure of the bed, when the map was made; and the depth proved, in fact, to be 182 feet.

The next winter a new rod was made and divided into feet and tenths of a foot, and marked in the same way as the other had been. Also, the measuring cross-hairs in the telescope of a new transit, with a magnifying power of about ten times, were made adjustable by screws, so as easily to be placed just so far apart that one foot of space cut off on the rod by two near cross-hairs should indicate a distance of one hundred feet; and the rod could be used at the same time for levelling, as there was a level on the transit telescope. This apparatus was used very successfully through the summer and autumn of 1864, and again in the autumn of 1865. In measuring important lines, every measurement was checked by a double observation, and every compass-angle roughly checked by reading also the angle of the vernier plate; so that no station was left until it was seen that no important error in reading had been made; a mode of checking that is much better than running over a line a second time. The screws that adjust the measuring cross-hairs are just behind the screws that adjust the middle horizontal cross-hair; and as the upper one was found to be exposed to being struck and turned by the limbs of trees or bushes in carrying the transit through the woods, and so making an error in the measurements before it was discovered, a cap, open on both sides, has been put over the head of this screw, to protect it completely. The telescope of a solar compass was also furnished with one fixed and one adjustable horizontal cross-hair for measuring, and was used successfully in this way with the rod just mentioned.

The same transit was also used in the autumn of 1865, with great success, for measuring underground in a coal mine, and it saved much disagreeable groping in the mud to count the links of a chain; and levels were taken at the same time, with one rod. The figures on the rod, in this case, were painted with red ink upon thin paper that had been fastened to strips of common window-glass by transparent varnish, such as photographers use on their negatives. Then another coat of varnish was poured over the paper, and another strip of glass was placed upon that. The glasses, with the paper between them, were then put into a long, narrow frame of pine wood, five-eighths of an inch thick and an inch and a-half wide in the clear, which formed one side of a long box, three inches and a quarter square inside. The box has neither top no

bottom, and its sides are so hinged together that they fold over upon each other when not in use, so as to protect the glass and take up less space. The back of the box has holes through it, to supply air to the lights; and either little mine-lamps, or candles in little tin sockets, are stuck in the wood of the back. This box was made 5 feet long; but for low mines, one might be made much shorter, say, a lantern 1 or 2 feet long (perhaps of tin), and for levelling, it could have a leg that would slide in or out, so as to raise the lantern to the required height from the ground. The inside of the wooden box may be painted white, to reflect the light well, or be lined with tin, and the outside may be painted black, so as to show less the black dirt of coal mines and the grease and smoke of the lamps.

One-half of full size.

The figures on this underground rod are the common Arabic numerals, made a hundredth of a foot thick throughout and very angular, so that each hundredth of a foot in their height is marked by an angle. Every tenth of a foot is marked with a number, instead of every other division, as on the two other rods. The feet are marked by the same figures, but they are made white on a red ground; and the red ground reaches half a tenth of a foot each way from the foot-mark, so that the feet are very conspicuous at a distance. The rod for use with the transit above ground has now been repainted with these figures, as they are much more convenient for reading. They are cut in a stencil-plate, and are, therefore, easily marked on the rod; it would be still more convenient to stamp them with a die. They are eight hundredths of a foot long, four hundredths above, and four below, the line, and the fifth is easily estimated by the eye at half-way between one figure and the next. Of course, a land surveyor could have the rod divided into links, and marked accordingly; or he could so adjust the cross-hairs, that a foot on the rod would answer to a chain on the ground. The rod is, then, in effect, marked with divisions a hundredth of a

foot apart, and a telescope that magnifies ten times should, for distances less than a furlong, be exact to $\frac{1}{2400}$, that is, at most, about three inches; and to $\frac{1}{1200}$ for distances between a furlong and a quarter of a mile; and with a telescope twice as powerful, should be about twice as exact, since the smallest divisions could be halved by the eye. The exactness, then, with a telescope that magnifies twenty times, is at least as great as that claimed for Porro's larger instrument. Telescopes that magnify only ten times, with this rod, would measure, on the whole, much more exactly than the chain. Of chaining, Wm. A. Burt writes as follows, in his, "Key to the Solar Compass," p. 35.

"Measurements with the chain and tally-pins are often very imperfectly performed by the chain men, and much more error is made than is generally supposed. It has been found by many trials, with as good men as can generally be obtained, that with two sets of chain men, instructed alike in the proper manner of keeping the chain level and straight on the line, and of setting the tally-pins plumb, as well as holding the ends of the chain to them, a difference has sometimes been made of 36 links," ($\frac{9}{2000}$) "and an average difference of 15 or 16 links to a mile," ($\frac{1}{500}$), "in common timbered land. But repeated measurements over the same mile, by the same chain men, and near the same time, will generally agree within 5 links" ($\frac{1}{1600}$); "yet, after several months' employment in the field, a measurement of this line may not agree so exactly. Again, the same chain men will make a different measurement to some extent, over swamps, marshes, wind-falls and thickets, when there is snow on the ground, and when there is none, in cold and in warm weather, effecting a change in the length of the chain, and by measuring fast or slow, the amount of error to each would be difficult to estimate."

It is seen that only in rare and favorable circumstances can a mile generally be chained within $\frac{1}{1600}$ of a second chaining. This precision of $\frac{1}{1600}$ is not more easily got by chaining, therefore, than the precision of $\frac{1}{2400}$ is got in measuring a furlong, at a single sight, with a telescope magnifying ten times; so that this telescopic measurement is at least one-half more exact than the chaining. But, as the error in reading the distance with the telescope is just as likely to enlarge as to lessen the true distance, the errors of several sights would tend to balance each other; in fact, the precision would increase as the square root of the number of sights. A mile measured in eight sights of a furlong each

would be almost three times as exact as one sight, say within $\frac{1}{7000}$. A mile measured in ten sights of 528 feet each would, with the same care, be exact within about $\frac{1}{7500}$; with twenty sights of 264 feet, within $\frac{1}{11000}$, or less than 6 inches. The exactness with a telescope magnifying twenty times would be twice as great. The striking advantage of the instrument, then, for exactness is unquestionable; indeed, as the exactness might be still further increased by measuring a number of miles in one line, and by painting the rod in black and white (the best colors for distinct visibility, and twice as easily seen as the red marks have been reckoned,) the instrument is well fitted even for quite exact geodesical measurements. The ease with which the measurements can be checked, so that large errors of reading are avoided, should also be borne in mind.

The general ease and quickness of telescopic measuring has always been recognized. The delays of chaining are saved; at the expense, however, of an addition to the telescopic work. Not only is the great trouble of training chain men avoided, but instead of two chain men with a rod, only one rodman is needed, whose duties are so simple (merely to hold the rod plumb in a good place) that he can also serve at times, as axe-man. As the observations at the instrument are more numerous, it is the more desirable, though not absolutely necessary, in topographical work, to have an assistant, to make all the readings to be noted by the head of the party.

The adjustableness, then, of the cross-hairs, and the easily legible marking of hundredths of a foot on the rod, by means of angular figures, or otherwise, make even greater exactness attainable than by Porro's improvements, without the excessive complications of his instrument, or its niceties in workmanship; and, at the same time, permits both levelling and measuring with only one rod. The rod lighted inside makes telescopic measuring and levelling easy under-ground, where chaining is peculiarly disagreeable. Such measuring is far more exact than chaining, as well as quicker and easier.

B. S. L.

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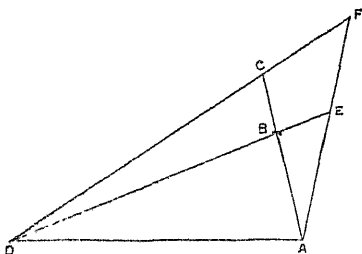
It should be noticed that the measuring rod should be very nearly vertical, otherwise the small error which arises from this will be greatly magnified in the estimated distance.

Thus if the rod (see *Fig.*) be inclined at a small angle $\beta$ (expressed in terms of the circular measure of the angle), we have CB = FE $\cos\beta = s\cos\beta$; where $s$ = distance measured on the staff (*see* notation in page 153).

Employing FE, the observed distance on the measuring rod, to find AD we get—

$$AD = FE \times n\cos^2\phi + \overline{f+d}\cos\phi$$
$$= n\,s\cos^2 \times \overline{f+d}\cos\phi$$

But employing CB = FE $\cos^2$ B, the true value of

$$AD = n\,s\cos^2\beta\cos\phi + \overline{f+d}\cos\phi.$$

$$\therefore \text{Error in AD} \times n\,s\cos^2(1 - \cos\beta) = n\,s\cos^2\phi \times \frac{\beta^2}{2}.$$

$$= AD \times \frac{\beta^2}{2} \text{ very nearly.}$$

Suppose that $\beta - 1° = \frac{3{\cdot}1416}{180} = \frac{1}{60}$ nearly.

Then error in $AD = \frac{AD}{7200}$,

and if $\beta = 2°$, then error $= \frac{1}{1800}$ of AD.

Whence we see that a deviation less then 2° of the measuring rod from the vertical will not produce a sensible error. But for greater deviations, the errors will sensible affect the correctness of the measurement. It will, therefore, be necessary to adjust the measuring rod by means of plumb lines, or otherwise.

J. E.

ROORKEE,
*April*, 1870.

# No. CCLXXI.

## IRON BRIDGES IN CEYLON.

*Memo. of the cost of scaffolding and fitting required for the erection of the Brotherhood Lattice Bridges; by* H. BYRNE, ESQ., *Provincial Assistant, Western Province, Colombo, Ceylon,*

I MAY observe that the cost of scaffolding for various spans may be taken to be directly as the span, varying only with the difficulty of procuring timber; and the cost of fitting the ironwork to be very nearly as the span, but not quite—the several pieces of bridges of small span being more manageable than those of large bridges.

The operation of fitting the girders is thus performed:—

*1st.*—Lay the bed plates at the proper pitch due to the camber of the girder, on a carefully adzed surface; the bed to consist of a single slab, if possible.

*2nd.*—Lay the bottom chord of each girder, bringing it to its proper camber by wedges. Insert all the screw bolts, but defer tightening them up till the whole of the ironwork is fitted.

*3rd.*—Fix the standards or uprights, the cross girders and the struts under these.

*4th.*—Lay the top chord, using at first only so many of the screw bolts as are needed to hold it in place till the diagonal bars are fixed.

*5th.*—Fix the diagonal bars.

*6th.*—Fix the bottom tie-rods.

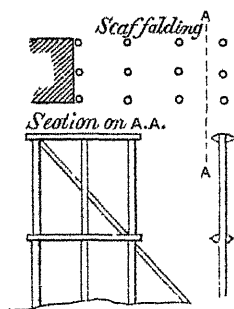
Operations 4 and 5 should be commenced at both ends and carried on towards the middle.

It is generally found when the diagonals are being fixed, that the bolt holes here and there must be rimered in order to make all the pieces fit: and sometimes they are enlarged with this view to the extent of perhaps a quarter of an inch. But supposing the manufacture to have been carefully attended to, it needs only care and patience, in adjusting the bottom chord to the proper camber, to render any enlargement of holes beyond rimering unnecessary.

It is only in this part of the process that difficulty or trouble ever arises.

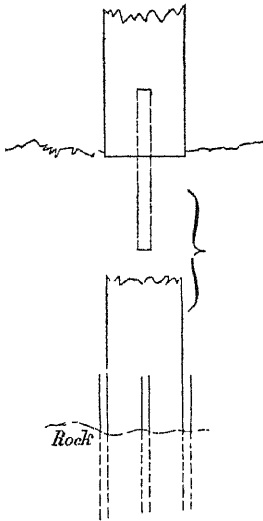
From 50 to 100 drifts should be provided to take the place of bolts temporarily, till the whole of the structure is fitted ready for finally screwing up the bolts.

When all the pieces are fitted truly, the whole of the screw bolts should be lightly screwed up; and then the wedge may be struck from under the bottom chord, working from the centre of span towards the two abutments.

It is advisable before commencing the operations, and in fact as soon as the whole of the ironwork is supposed to be delivered on the ground, to ascertain that every piece of the ironwork, bolts and nuts included, is forthcoming; and this is best done by laying on a piece of level ground in order, the several pieces of each chord in the position it must finally occupy. The other pieces (standards, diagonals, &c.) need only be counted and the number compared with the plan.

The whole of the operations, for a bridge of the largest span, may be performed easily in three or four weeks.

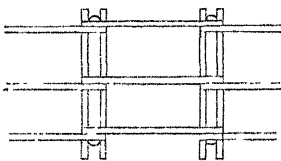
In the case of the Ratnapura bridge, the wedges under the centre span were removed on the twelfth day after the first piece of bottom chord was laid.

The scaffolding consists of rows of piles, three in each row; at intervals of 12 to 15 feet, a cross sill is laid over the top of each row; and where the height exceeds 30 feet, another about half way down; a double sill (*i. e.*, one on each side) is preferable. One should be fixed as a brace to each row of piles, and where there is considerable height, or a likelihood of a flood occurring, a strut on the down stream side is preferable.

In a soft bottom, the piles must be fixed in place by means of a small pile engine. In a rock bottom, it is sufficient either to step each pile a few inches into the rock, or fix it by means of a stout piece of bolt-iron, one half run into the core of the pile, and the other into a hole bored with a jumper in the rock; and in either case, to secure it further by four or five pieces of 1 inch or $1\frac{1}{4}$ inch bolt-iron, 18 inches in length, driven about 10 inches into the rock and close round the foot of the pile. The piles ought to average 15 inches in diameter, and to be not less than 12 inches at the top. Each pile to consist if possible, of a single log; but where this is not obtainable, the pile may be built of several pieces, as shown in sketch, breaking joint, and hooped and bolted together.

All the timber so far should be directly under the girders, or only a few inches outside the girder line.

The beams are then laid loose in three lines, one over the centre pile and the two others as nearly as possible under the girder lines.

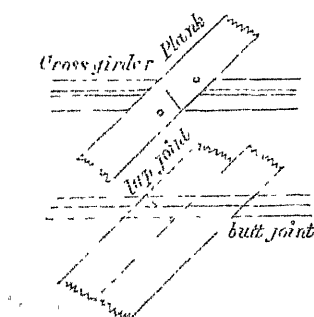
The whole of the timber so far, to be rough as taken from the jungle, and merely adzed where two pieces are brought in contact.

The level of the pile heads and top sills having been roughly adjusted to the camber of the iron-work, and the longitudinal pieces being, as we may suppose, of uniform scantling, the whole of the framing is covered with planks (usually the planks intended for the bridge deck) laid across to form a stage for the men to move about on; and upon these planks the bottom chord of the iron-work is laid.

It is expedient to fix on this planking, and at intervals of 5 or 6 feet along the line of each girder, uprights, to indicate the exact level at each spot of the bottom chord of the girder, as due to the camber to be given to it.

It is usual to allow, in erecting the scaffolding, for a camber in the girders slightly in excess of that designed by the manufacturer, to allow for settlement after the scaffolding is removed; but for girders of the greatest length, an allowance of an inch over the designed camber will be quite ample.

Since the strain on the bottom chord is wholly tensile, the straighter that member is the better, and the only conceivable object of cambering it is—1st, To avoid the appearance of depression which would probably result from making it perfectly straight; and, 2nd, To allow for settlement in fitting. Both objects would be secured were the camber reduced to one-half of what it is now, or say at most 6 inches for a span of 150 feet, and the camber for smaller spans to be such as to give, in all cases, a curve of the radius due to a chord of 150 feet and versed sine of 6 inches.

The chief practical objection to an excessively cambered girder is, that where two or more pairs of them are used in one bridge, a most painfully sensible ridge and furrow character is given to the roadway. This can be remedied in construction only by packing under the planking, at and near the junction of the two sets of girders; but the result of this clumsy mode of remedying the defect is to enhance very considerably the trouble of renewing and repairing the roadway.

The upward curve given to the top of the cross girder, while being unnecessary for strength, is the cause of injury, by straining the stiff timber used in this country for planking. There is a constant tendency in the planks (which are laid diagonally across the bridge) to start at the ends, and as the planks are required to be kept so far apart as to admit of air and water passing between them, the barrelled cross section now given to the road, as the result of the shape of the girder, is unnecessary for drainage. It is found too that in wet weather, when the planking is of course slippery, it is most dangerous for a horse to pass along any where out of the centre line of the road.

The upper web of these cross girders is not wide enough for the mode of pinning the ends of planks which experience has shown to be the best. It ought to be full 7 inches wide, so as to

give a bed to the whole length of a square butt joint in 10 inches planking. At present such planking must either be lap-jointed, or the butt joint does not leave enough room for a bolt at the end of each plank.

H. B.

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MEMORANDUM BY THE DIRECTOR.

In order to reduce the thickness of the planking by reducing the length of bearing, I have introduced light T iron bearers, as sketched, on the cross section (*see* General Drawing of the Bridge). This does away with the objectionable camber of the planking, and the planking is laid parallel to the cross girders.

It is desirable not to have the planks too wide, otherwise they will warp. I restrict them now to a maximum of 6 inches chamfered at the edges, each plank being laid with two distance pieces, $2'' \times 2'' \times \frac{1}{2}''$, nailed on its edge, so as to keep an air space of half an inch between each plank.

| Bridge and Span. | Cost of Fitting Iron-work. | | | Cost of Scaffolding. | | |
|---|---|---|---|---|---|---|
| | RS. | A. | P. | RS. | A. | P. |
| Ratnapura, 3 spans of 140 feet each, .. .. | 121 | 1 | 9 | 576 | 13 | 8 |
| Kahawatta, one span 140 feet, .. .. .. | 36 | 14 | 7 | 249 | 12 | 11* |
| Koroowitty, " .. .. .. | 45 | 0 | 0 | 35 | 0 | 0 |
| Yatteantotte, " .. .. .. | 48 | 4 | 1 | 135 | 16 | 3 |
| Ratotte, one span 100 feet, .. .. .. | 32 | 0 | 0 | 69 | 0 | 0 |
| Damboloya, " 80 " .. .. .. | 70 | 0 | 0 | 124 | 0 | 0 |
| Nalande, " 100 " .. .. .. | 38 | 0 | 0 | 65 | 0 | 0 |

Memo. of the cost of Brotherhood's Iron Lattice Bridges delivered at Colombo (Ceylon).

| | | | |
|---|---|---|---|
| 60 feet | £370, weight | $15\frac{1}{2}$ tons, | width of roadway 15 feet. |
| 80 " | £597 " | $25\frac{1}{2}$ " | |
| 100 " | £846 " | $35\frac{1}{2}$ " | |
| 120 " | £1189 " | $51\frac{3}{4}$ " | " 18 feet. |
| 140 " | £1335 " | 65 " | |
| 150 " | £1600 " | 75 " | " 18 feet. |

* This expenditure covered also the cost of centering for two 30 feet arches; £180 may be set down as the cost of the scaffolding for the iron-work.

G. M.

# No. CCLXXII.

## AMERICAN AND FRENCH ROAD COVERINGS.

By Capt. J. M. Heywood, R.E.

*Stone Block Paving*—(Syenite or Trap).—The subsoil is first removed to the depth of 12 inches below the top line of the proposed pavement; all holes or inequalites are filled to the proper level with sand or gravel, well rolled or rammed. On this foundation, a bed of clean, sharp sand or gravel is laid to the depth necessary to bring the stone blocks to the proper grade.

The stone blocks are laid at right angles with the line of the street. Each course consists of blocks of a uniform width and depth, and is so laid that all longitudinal joints shall be broken by a lap of at least 2 inches. The stone blocks usually measure from 4 to 8 inches in length, and from 4 to 6 inches in breadth; on the upper surface, the minimum allowable breadth or length on the base is 3 inches; the depth varies between 6 and 8 inches. When the blocks are laid, they are covered with clean, fine sand, which is raked into all the joints till they are filled: the blocks are then rammed to a firm unyielding bed with a uniform surface, and to the proper grade and crown.

*McGonegal Pavement.*—The subsoil is first removed a depth of 12 inches below the surface of the pavement to be laid; all holes or inequalites are then filled to the proper level with sand or gravel, well rolled or rammed. On the bed thus prepared, a layer of 3 inches of sand is spread over the whole surface, and rolled with a roller weighing not less than 1500 lbs. When brought to a uniform depth of 9 inches below the pro-

posed grade of the wooden pavement, this sand bed is covered with a layer of concrete.

The concrete is composed of gravel and mortar, mixed in the proportions of 4 parts of clean and firm gravel to $2\frac{1}{2}$ parts of mortar. The mortar is made of $1\frac{1}{2}$ volumes of sand to 1 volume of cement, mixed with a proper quantity of water. The dimensions of the gravel are fixed so that the largest stones shall pass through a ring $1\frac{1}{2}$ inches in diameter on every side. It is screened, when dry, over a screen with meshes of one-quarter of an inch square, to take out the fine particles. The gravel thus prepared is thoroughly mixed with the mortar, in the proportion of 4 volumes of gravel to 1 volume of cement used in the mortar.

The concrete is laid over the sand bed to a depth of at least 2 inches.

Over the concrete, a flooring of sound white pine boards, free from sap, 1 inch thick, is laid lengthwise with the street, and 1 inch apart. The under side of the boards is covered with hot coal tar previously to being laid, and the upper side is covered in like manner after they are laid.

Upon this flooring, wooden blocks are laid. The blocks are of Southern yellow pine or white pine, free from sap, 3 inches thick, 6 inches deep, and from 4 to 16 inches long on the surface. Each block is pierced with circular holes $3\frac{1}{2}$ inches deep and $1\frac{1}{2}$ inches in diameter, spaced from $1\frac{1}{4}$ to $2\frac{1}{4}$ inches apart. In each block, a triangular groove is cut in the middle on each side, extending through the block, so that when two blocks are placed together there is a square opening $1\frac{1}{4}$ inches square to receive a dowel or key. The key is of Southern yellow pine.

The blocks are set on end in parallel courses transversely with the line of the street. Each block to two-thirds of height at least, and each dowel or key before being laid, is thoroughly dipped in hot coal tar. The perforations in each course of blocks are filled with a composition of clean roofing gravel and hot coal tar, thoroughly mixed. The roofing gravel is thoroughly dried and is mixed warm so as not to chill the tar. The coal tar is boiled down and thickened with pitch so as to be tough and fibrous when cool, and not brittle even in cold weather. It is applied hot and in sufficient quantities thoroughly to penetrate and fill all the joints and circular holes. The whole surface of the pavement, as rapidly as it is completed, is covered with hot coal tar, and coated with a layer of fine sand not less than three-fourths of an inch thick; after twelve days, this sand is swept off the surface and carted away.

*Fisk Concrete Pavement.*—The road bed is prepared as described in the former cases—on the foundation thus prepared the pavement is laid as follows:—Broken stone, coarse gravel or iron cinders, any, or all, of them, in the proportion of 70 per cent. are mixed with 25 per cent. of coal ashes. The former materials are sized so as to pass through a 2-inch ring by the largest dimensions. The coal ashes are screened over and through a screen with meshes not more than 1 inch square. The coarse part of the material passed over the screen is, after being thoroughly dried, mixed with about equal parts of pine and coal or coal tar (warm or cold), until every part of the earthing material is well and thoroughly smeared with tar. The material thus prepared is then laid on the road bed in layers of 2 to 4 inches, to the extreme thickness of 4 inches over the road bed, and every layer rolled with a heavy roller. The finer portion of the material (broken stone, coarse gravel, iron cinders and coal ashes) which has passed through the screen, is then, after being thoroughly dried, also mixed with pine and coal, or pine or tar pitch, so as to make it plastic, and then spread over the fresh coal 2 inches in thickness, and covered with a coat of sharp sand, sufficient to cover the surface of the pavement. Twelve days after the completion of the pavement, the covering sand is swept into heaps and removed.

*Nicholson Pavement.*—The road bed is prepared as in the previous cases. It is then covered with sound pine boards, 1 inch thick, laid lengthwise with the line of the street, the ends rest on similar boards laid transversely from curb to curb. The flooring is well tarred on both sides with hot coal tar, brought to a proper consistency with pitch, so as to be tough and not brittle when cold.

On this flooring, blocks of sound Southern yellow pine, or white pine, $2\frac{3}{4}$ inches to $3\frac{1}{4}$ inches thick, 6 inches deep and between 4 and 14 inches long, are set on end in parallel courses transversely with the line of the street. All the blocks in each course are of exactly the same thickness and width, and each block, before laying, is dipped to half its height in hot coal tar. Each course is separated by a course of pickets placed at the base of the block, and the whole made firm by nails driven about 18 inches apart. The pickets are of sound common pine boards, 3 inches wide and three-quarters of an inch thick. The spaces between each course of block above the pickets are filled in with a composition of clean roofing gravel and hot coal tar, thoroughly mixed and rammed. The roofing

gravel is free from all fine particles, and is thoroughly dried and mixed warm with the tar. The coal tar is prepared as has been previously described, and is used in quantities of not less than 3 gallons to the square yard.

FRENCH ROADS.—*Paved Roads.*—The foundation is composed of sand, rammed in layers $2\frac{1}{3}$ inches deep, until a consolidated depth of 8 inches is obtained; on this the stones are bedded; these stones are from 8 to $9\frac{1}{2}$ inches long and $4\frac{1}{2}$ to $5\frac{1}{2}$ inches broad on the surface, and $6\frac{1}{4}$ inches deep. The joints are then filled up with sand, and the whole well rammed. A layer of sand, 1 to $1\frac{1}{2}$ inches in depth, is then spread over the whole. The curve of the road surface generally equals $\frac{1}{50}$ of the breadth.

*Macadamised Roads.*—The foundation of the road is first consolidated so as not to move under the roller when fully weighted; it is then covered with an uniform layer of broken stone, varying from 10 inches on the Imperial roads, to 4 inches on the ordinary roads. The roller, at first unweighted, is passed over it; this is repeated a second time, half the movable weight being attached; subsequently, the whole weight is completed, and the rolling continued until no further impression is made on the material.

When the unmixed materials have thus been consolidated, the binding matter is spread on the surface in successive layers, the roller being passed over each time. When the binding material no longer enters the interstices, the surface is saturated with water. When the water has penetrated into all parts of the road, fresh binding material is added on the top, and the roller is passed over the road until it makes no impression. The road is then ready to receive the traffic. At first great care has to be exercised to efface the ruts, and keep the whole surface of the road equally in use ; and, above all, to maintain the road in a constant state of dampness, till all signs of settling have disappeared. The surface of the pavement, when completed, is covered with hot coal tar and immediately coated with fine sand and gravel, mixed in about equal proportions, and not less than three-fourths of an inch thick. Twelve days after the completion of the pavement, the sand is swept into heaps and removed.

This is a description of pavement now very largely adopted in the United States.

J. M. H.

# No. CCLXXIII.

## THE METRICAL SYSTEM IN THE PUBLIC WORKS DEPARTMENT.

*Calcutta, December 7th,* 1869.

DEAR SIR,—The Government having determined to adopt the kilogramme as the unit of weight for British India, it may be anticipated that this change will be carried out shortly, and that it will be brought into operation on the Railways among the first of the public bodies to be dealt with.

It appears to me almost impossible to adopt any other conclusion than that, if the metrical unit of weight is adopted by a compulsory law, as is intended, it will be practically necessary *for engineering purposes* to adopt the metrical unit of length simultaneously. All tables for engineering purposes in use in England are based upon the English units of measurement, the yard or foot, and the pound or ton. French tables could, for most purposes, be at once made applicable if the metre and kilogramme are introduced simultaneously, whereas if a bastard system of feet for lineal measurement, and kilogrammes for weights, were adopted, it would be necessary to obtain an entirely new series of tables, which must be specially computed for the purpose. It is not easy to see how such a result could be obtained, even if it were desirable.

It should be added that it seems to me that the metrical unit of weight having been adopted in India, the adoption of the other metrical units must follow; and, therefore, that by now accepting the metre with the kilogramme, there is no risk of any eventual further change; on the contrary that this step would make the change once for all.

It may not be generally known that the Report of the Royal Commis-

sion presented to Parliament this year plainly advocates the adoption of the metrical system of weights and measures in Great Britain, and that it seems now hardly possible that this change can be delayed much longer in that country. This affords another argument in favour of making the change of system here complete, and once for all, when the change of weights is ordered by the Government

I shall be thankful if you will be so good as to give me your opinion, therefore, on the expediency of carrying out the change of system simultaneously in the department to which you are attached, in respect to both the units of weight and length, when the orders are issued for the change of the weights.

The Bill to carry out the change is in my charge, and will shortly be brought before the Legislative Council of the Governor General, and I shall esteem it a favour if you will give me a reply to the above question at your earliest convenience.

It is to be clearly understood that the above remarks apply exclusively to Engineering departments under the Government, Municipalities, and the Railway Companies. There is no intention of adopting any present change for the general public, excepting in the Weights.

I have &c.,
R. STRACHEY, Colonel, R.E.

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*Reply to the above.*

I do not clearly understand, from Colonel Strachey's Circular letter, whether he wishes to discuss the expediency of introducing the Kilogramme as the Unit of Weight in all Engineering Projects and Calculations in future, or whether, *taking for granted that the Kilogramme is to be the Unit of Weight*, we are merely to discuss the expediency of a simultaneous adoption of the Metre, as the corresponding Unit of Length.

So far as I understand what has been sanctioned by the Home Government, and which is now to be embodied in the proposed Bill, all that has been hitherto contemplated is to introduce a uniform standard Unit of Weight for all India, and that this unit is to be identical with the Kilogramme—(whether it will be called a Kilogramme or a Seer matters

little)—that this standard Unit is to be made compulsory with respect to all Government Departments, and will be *gradually* introduced into all wholesale and retail transactions throughout the country.

But this change will in no way specially affect Engineering Works and calculations. At the present time, all such calculations are made in pounds or tons throughout India, quite irrespective of the fact that seers and maunds are the weights used in commerce, and that the pound and ton are, as regards India, merely theoretical weights. Where the two questions touch each other, the seer is held to be practically 2 lbs., and the maund to be 80 lbs. (28 making a ton) and this really meets all practical requirements. A slight alteration, therefore, in the value of the seer, which is really all that seems to be at present intended by Government, will in no way affect Engineers.

But, if it is seriously contemplated to introduce the Kilogramme authoritatively in place of the Indian Engineer's (theoretical) pound, and to insist upon all calculations and estimates being made in that denomination, I think such a measure is open to very grave practical objections, especially at the present time.

The Government are now importing large numbers of English Civil Engineers, and the connection between the Indian, and the English, Engineer, is becoming closer and closer every day. The new Government Railways cannot be carried out without large importations of materials and plant from England, all of which will necessitate much correspondence and calculation on the subject of Horse-power, Breaking Weight, Strains, &c. Such calculations, if based on the Kilogramme instead of the pound, would cause much embarrassment and trouble, and would practically require to be translated for the Home Engineer and Manufacturer. Moreover, all English Tables of Weights, Strength of Materials, &c., &c., would be useless without a troublesome calculation in each case.

It is true that by the introduction of the Metre, French tables might be used instead, but this would first involve a certain amount of translation, and it would also necessitate the comprehension of two units in place of one, and the second of which bears no approximate relation to the English unit. Moreover, this would also cut off the Engineer from English Tables of Earthwork, Measurement of Timber or Iron, and the like.

Now, it is not too much to say, that questions of Stress and Strain, as

involved in calculations of Roofs, Bridges, &c., are only just emerging from the region of empirical practice. Many of our Engineers have very little acquaintance with the subject, and, if to its inherent difficulties, we wilfully add others, such as would be involved by the introduction of new units of Length and Weight,—and thereby to a great extent cut off a large body of Engineers in this country who are engaged in practical work, from the eminent theorists in England, who are just succeeding in bringing practical results within the domain of accurate laws, a great dis-service will, I think, have been done to the cause of Engineering Science.

No doubt, the pound might be banished by legislative or departmental enactment, and the Kilogramme forcibly substituted; but in practice, Engineers would think and work in pounds, and would then send up the result of their calculations in Kilos.

A great step will have been gained by the authoritative introduction of a uniform standard weight for all India, which will gradually supersede the various local seers. Of that step, Engineers will share the benefit in common with the rest of the public, and no doubt in various ways in their correspondence with other Engineers in different parts of India; and incidentally, perhaps, in their relations with French Engineering. But, so long as the Indian Engineer has such close relations with, and is so dependent upon, the English Engineer, it appears to me expedient to postpone the alteration of the Standard Units of Weight and Measurement, until that alteration shall first have taken full effect in England.

In what I have said above, I have not been in the least arguing against the abstract superiority of decimal units of weight and measure, such as the Kilogramme and Metre over the common English denominations. And if it should be decided to set aside the foregoing considerations, and to enforce peremptorily the adoption of the Kilogramme in all Engineering Projects, Estimates and Calculations, in lieu of the pound, then I think that the adoption of the corresponding unit of measurement, the Metre, should be simultaneously enforced.

The several Engineering heads under which the Units of Weight and Measurement touch each other are as follows:—

1. Questions involving (at present) the foot-pound—which belong to Mechanical Engineering and to considerations of the units of work or labor.

2. Questions involving the square foot and pound—as those regarding the quantity of fuel, and evaporating surface of boilers, &c.
3. The absolute weights of materials of all kinds—which are usually given in pounds per cubic foot.
4. Strains upon the several parts of structures, such as roofs and bridges—which are estimated in pounds or tons per square foot.
5. Strains on iron or timber—estimated in pounds per square inch.
6. Strength of materials, such as crushing or breaking weights—reckoned in pounds per square foot or square inch.

In all these cases, if the Kilogramme is to be substituted for the pound, English tables could only be used (as said above) by a calculation made in each particular case for converting the pounds into Kilos, and *vice versâ;* but practically no doubt the Kilo would be taken as 2 lbs., and the decimal neglected. In some cases, the resulting difference would be of no importance in practice, in others, involving large numbers, it would be.

By introducing the Metre, French tables could be used without alteration; besides, however, the labor of translation, it would be very difficult for an Engineer of 20 years standing, who had been accustomed to think in feet or yards, to think in Metres instead, and the difference between the yard and the Metre is more serious than that between 2 lbs. and the Kilogramme. I think the chances are, he would work out his calculations in feet and pounds and then translate their results into Metres and Kilos. But the rising generation of Engineers would doubtless adopt the new units. Before the change is actually made, the new tables should be prepared in English, and for the benefit of older hands, the corresponding equivalents in English units should be given.

It would also seem desirable, if new Units of Weight and Length are adopted, to add the adoption of the corresponding Fluid Unit. The Engineering questions involved are, certainly, far less numerous than those above enumerated—as Indian Hydraulics involve the cubic foot only—but projects for water supply of towns are becoming more numerous, and these involve the " gallon" unit. Questions of the cost of lift of water, for example, by steam, would involve at once the pound (of fuel)—the foot (of lift)—and the gallon (lifted). At present a gallon is taken as 16 cubic feet or 10 lbs. But if any large change is made, it would be as well to make it complete.

It is, no doubt, greatly to be desired that authoritative standards for Lineal, Square and Cubic Measure should be adopted for all India. At present, English and Madras Engineers calculate Earthwork and Water discharges by the cubic yard, while Bengal and Bombay Engineers use the cubic foot. The yard is not often used as a linear measure, but feet and decimals of a foot—feet, inches and twelfths—feet, inches and decimals—are all employed. The Acre is pretty extensively employed, but not universally, amongst Engineers—while the District Officers with whom Engineers are constantly involved, stick pertinaciously to the Beegah, which varies in almost every district.

As to English Engineers, what with chains of 66 feet—English, Irish and Scotch acres—" hundreds" of deals or nails—" loads " of bricks, lime, planks, sand and timber (all differing)—" rods" of brickwork, and other trade or local denominations, confusion is worse confounded.

It is obvious, however, that much of this might be amended by judicious legislative enactment, without going to the extreme length of altering the whole of the Units. I am disposed to think that, in our admiration of the decimal system, we are rather apt to include a perference for the Metre and the other corresponding denominations, simply, because they are decimally divided—forgetting that the one does not necessarily involve the other. There is no particular advantage that I am aware of in having the unit of length any fractional part of the Earth's diameter—especially as the accepted value of this latter quantity is always liable to correction with the more perfect instruments now used in Geodetical operations—any arbitrary value would do equally well. In India, the foot decimally divided might replace the yard and inch; and the various local beegahs and kosses should certainly be done away with in all Government proceedings.

For the same reason that I would not as yet replace the Foot by the Metre, I do not see the way to replacing the Acre and the Mile by the Hectare and the Kilometre. So long as our relations are so closely connected with England, I think such changes must wait for those of the mother country. Distances of Railways given in Kilometres and Areas of Irrigation estimated in Hectares, would convey no distinct impression to the minds of English Shareholders and English M.P.'s.

But the adoption of uniform Standards of Length, Area and Cubical Capacity for the whole of India, would be so great an advantage that the

local disadvantages attending it would I think be far out weighed by the gains.

J. G. M.

ROORKEE,
*December* 22*nd*, 1869.

*Note.*—The late Col. Dyas, who was a strong advocate for the decimal system, introduced a new mile of 5,000 feet in the Punjab Irrigation Department, which is no doubt a convenience. The present acre is 43,560 square feet, and a Hectare is 2·471 acres. If a new acre of 50,000 square feet were introduced, a Hectare would be equivalent to 2·153 of these acres, and the nearer approximation would make the subsequent change to the Hectare more easy—while 500 acres would go to the square mile instead of 640 as at present. The new mile would be rather more than 1½ Kilometres.

# No. CCLXXIV.

## FOURACRES' STIRRUPS FOR BLOCK SINKING.

*From* H. C. Levinge, Esq., *Superintending Engineer, Soane Circle, to* Colonel F. H. Rundall, R.E., *Chief Engnieer, Bengal Irrigation Department.*—Dated the 31st March, 1870.

I forward, for your information, tracing of one of the blocks of the Soane Anicut fitted with the stirrups invented by Mr. Fouracres, Officiating Executive Engineer of the Workshop Division, with a description by the same Officer of the method of using them.

The plan is so extremely simple and ingenious that I consider it deserving of special notice; by means of this expedient, the flexible bamboo curbs are rendered quite rigid and firm.

### Memo. by Mr. Fouracres.

The method employed to secure the blocks is very simple; a piece of flat iron $2\frac{1}{2}$ inches by $\frac{1}{2}$ an inch is pushed under the bamboo curb on which the block is built, so as to project slightly on each side of the block; at each end of the stirrup, holes are punched, through which bolts, $\frac{3}{4}$ of an inch diameter, are passed; the inside bolt has a head below the iron stirrup; the other is simply hooked into the outer hole.

On the top of the masonry block, planks are placed, as shown in the sketch, and to these the bolts are fixed; the block is thus rigidly supported.

The method of removing the bolts and stirrup is as follows:—The nuts on the tops of the bolts are first unscrewed; the outside bolts are then

knocked down slightly into the sand, so as to disengage the hook from the hole; when this is done, the inside bolts and stirrup are easily drawn up, as the removal of the sand leaves a hollow under the block, as shown in section; the outside bolts are also drawn up, and the operation, which does not occupy five minutes, is complete; the stirrup and bolts are of course available for another block.

C. F.

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# No. CCLXXV.

## PRACTICAL GAUGING OF RIVERS.

*By* GENERAL ABBOT, *U. S. Engineers* [*Communicated by* CAPT. J. M. HEYWOOD, R.E.]

THE following remarks, made by General Abbot (one of the joint compilers of the Report upon the Physics and Hydraulics of the Mississippi River) before the Essayon Club of the Corps of United States Engineers, will be found of interest.

*Practical gauging of Rivers.*—For practically gauging large rivers, the following has been found to be the best plan:—A locality is selected in a straight portion, where the water flows smoothly and without obstruction. A base line, about 200 feet long, is laid out parallel to the current, and the exact cross section in front of the base is determined by careful sounding. To obtain the discharge, two theodolites are established, and the angular distance from, and time of transit past, each end of the base, is noted for numerous floats well distributed between the banks. On the Mississippi, to observe 75 floats was found to be a good day's work, for a party of two engineers and eight boatmen, with two boats; the maximum day's work was to observe 120 floats.

The floats should be made double; the surface float being a minute tin ellipsoid,—a piece of cork,—or some other small light body bearing a little flag. The lower float may be a large box or keg without top or bottom, kept upright by lead ballasting; or better yet, because lighter, two sheets of tin bent at right angles and soldered together at the bend, so as to make all the angles between the fans right angles. The essential conditions are that the lower float shall so greatly preponderate in area over

the upper, and shall be connected by so fine a wire or cord, that its rate of movement shall govern the whole combination.

The centre of the lower float should be placed at the mid depth of the stream in each vertical plane of transit, because the rate of movement will then be unaffected by wind whether blowing strong or gently, up-stream or down-stream. It is sometimes a little troublesome to adjust to mid depth in the different planes of transit, but with a tolerably uniform and symmetrical cross section, the average mid depth of the river may be adopted for all the floats without sensible error.

The exact level of the water surface on a permanent gauge rod should be carefully noted, when the observations begin and terminate.

The following is the method of plotting the results thus obtained, and deducing the discharge per second.

Upon a sheet of section paper, the base line and two perpendiculars, across which the times of transit were noted, are laid down. From the recorded angles and a table of natural tangents, the distances from the base line to the points at which each float passed both lines are plotted. These points being connected, indicate the paths of the floats. Upon each path, the seconds of the transit, *i. e.*, the difference between the two recorded times of transit, are written. These seconds of transit are next examined, and the total width of the river is marked off into as many divisions as it seems proper to assume are traversed by water moving with sensibly unvarying velocity. On the Mississippi, the width of these divisions was uniformly assumed at 200 feet, the total width being about 2600 feet. A mean of the seconds of transit of all the floats in each division is next taken, and when reduced to velocity in feet per second, is adopted as the mid depth velocity in that division.

A mean of all these mean mid depth velocities, interpolations being made if any are missing, closely approximates to the mean velocity of the river, provided the divisions are equal in width. This method of deducing the mean velocity from the mean mid depth division velocities, involves two errors which nearly balance each other, viz., the inequality in area of the divisions, and the difference between the mid depth and the mean velocity in any vertical plane. The correction ratios for these errors are respectively about 0·93 and 0·98 in large rivers, giving a resulting mean velocity $\frac{0·93}{0·98} = 0·95$ times the true value. The ratio 0·98 varies for natural channels between the limits 0·92, for a depth and mean velocity of 1 foot, and

0·99, for a depth of 80 feet, and mean velocity of 8 feet per second. The ratio 0·93 is nearly constant for ordinary river channels; its law of variation is unknown.

If very exact computation is required, as for instance, in testing the constants of a formula; the "divisions" are laid down on the plot of cross section of the river and the area of each is computed for the second when the velocity observations were made. The different "division" mid depth velocities, including interpolations if any are wanting, are then substituted successively for $V_{\frac{1}{2}D}$ in the expression $V_{\frac{1}{2}D} - \frac{1}{12}\sqrt{bv}$, in which V is the mean velocity of the river, D the mean depth of the division and $b = \frac{1·69}{\sqrt{1·5 + D}}$; each result is multiplied by the corresponding area of cross section, and finally the sum of these products is placed equal to the products of V by the total area of cross section. The resulting equation contains $V.\sqrt{v}$ and known terms, and hence may be readily solved. The lesser root is the true mean velocity of the river.

A mean velocity intermediate in accuracy to those given by the two methods just described, may be computed by substituting the grand mean of the different mean "division" velocities, including interpolated velocities, if any are missing for $U_{\frac{1}{2}r}$ in the following equation, in which the value of $b$ is that given above, D being replaced by $r$, (the quotient of $a$ the area of cross section divided by $p$ the wetted perimeter, both in feet.) This method is simple and quite exact in ordinary river sections, but should not be applied to a rectangular section.

$$v = \{ (1·08\ U_{\frac{1}{2}r} + 0·002\ b)^{\frac{1}{2}} - 0·045\ \sqrt{b}\ \}^2$$

The formula given by General Abbot to determine the discharge of a river on any given date, is the following :—

$$v = \left\{ \sqrt{0·0081\ b + \left(\frac{225\ a\ \sqrt{s}}{p + W}\right)^{\frac{1}{2}}} - 0·09\ \sqrt{b} \right\}^2$$

Where $v$ = mean velocity.

$a$ = area of cross section.

$p$ = wetted perimeter.

W = width.

$b = \frac{1·69}{\sqrt{r + 1·5}}$

$r$ = mean radius or $\frac{a}{p}$

$s$ = Sine of slope of water surface corrected for bends; its

numerical value is found by dividing by the total distance between the level stations, measured on the middle line of the channel, the total fall between them; after subtracting the value of $h'$ in the following formula for bend effect, in which N represents the number of angles 30° each of the mid channel line, $h' = \frac{v^2 \text{ N. } \sin^2 30^\circ}{194}$. Of course the method of successive approximation must be used in finding the value of $v$ in this formula.

The variables which enter these formulæ require a knowledge of the mean cross section, and a map of the channel between two points of the water surface A and B whose difference of level is exactly known. Whenever practicable, A and B should be located on a straight and regular portion of the river, the effect of bends being thus eliminated; as this is not always possible, owing to the very gentle slope in water surface of most natural streams, and especially of large rivers, the general case will be considered and bends be assumed to exist between A and B.

The field operations will consist in making a survey of the channel, including numerous soundings between two permanent bench marks, placed near the water at the points A and B, and in running a line of levels with the most extreme accuracy between these benches, so as to fix their relative level within a small fraction of an inch. These points A and B must be located with care, as far apart as practicable, and distant from any eddy; and be placed where the current on the bank flows with equal velocity. The latter condition is necessary, because water in motion exerts less pressure than when at rest; and if it moved rapidly past one bench and was nearly stationary at the other, a difference of level which has nothing to do with the motive power of the stream would vitiate the observation. These surveys completed, a frequent gauging of the river can be made at trifling expense. The water surface has only to be referred, at A and B, to the bench mark by accurate levels. Two precautions must not be neglected in such operations. The observations must be *simultaneous*, and *calm* days must be selected.

The following formulæ give the value of each variable in the equation above in terms of the others and known quantities. Z is equal to $0{\cdot}93\ v + 0{\cdot}167 \sqrt{bv}$, and when $p$ is not known by measurement, it may be assumed to be $1{\cdot}015$ W.

$$s = \left\{ \frac{(p + \text{W})\,\text{Z}^2}{195a} \right\}^2$$

$$a = \frac{(p + \mathrm{W})\,\mathrm{Z}^2}{195\,\sqrt{s}}$$

$$p + \mathrm{W} = \frac{195\,a\,\sqrt{s}}{\mathrm{Z}^2}$$

For small streams, General Abbot modifies the formula given above, and produces the expression—

$$v = \left\{ \sqrt{0{\cdot}0081\,b + \left(\frac{225\,a\,\sqrt{s}}{p + \mathrm{W}}\right)^{\frac{1}{2}}} - 0{\cdot}09\,\sqrt{b} \right\}^2 - \frac{2{\cdot}4\,\sqrt{v'}}{1 + p}.$$

or putting $\mathrm{M} = 0{\cdot}0081\,b$.

$$\mathrm{M}' = \frac{2{\cdot}4}{1 + p}.$$

$$v = \left\{ \sqrt{\mathrm{M} + \frac{225\,a\,\sqrt{s}}{p + \mathrm{W}}} - \sqrt{\mathrm{M}} \right\}^2 - \mathrm{M}'\,\sqrt{v'}$$

The symbols all have the same significations as noted before; all are expressed in feet.

$v'$ is the value of first term in the expression for $v$.

For streams larger than 50 or 100 feet in cross section, the term involving $\mathrm{M}'$ may be dropped, and for large rivers exceeding a dozen or twenty feet in mean radius, M, but not $\sqrt{\mathrm{M}}$, may be neglected.

The following table is given to facilitate the application of this formula for mean velocity.

| r. | M. | √M. | P. | M'. | Log M'. |
|---|---|---|---|---|---|
| 1 | 0·0087 | 0·0930 | 5 | 0·400 | 9·602060 |
| 2 | 0·0073 | 0·0855 | 6 | 0·343 | 9·535294 |
| 3 | 0·0065 | 0·0803 | 7 | 0·300 | 9·477121 |
| 4 | 0·0058 | 0·0764 | 8 | 0·267 | 9·426511 |
| 5 | 0·0054 | 0·0733 | 9 | 0·240 | 9·380211 |
| 6 | 0·0050 | 0·0707 | 10 | 0·218 | 9·338456 |
| 7 | 0·0047 | 0·0685 | 12 | 0·185 | 9·267172 |
| 8 | 0·0044 | 0·0666 | 14 | 0·160 | 9·204120 |
| 9 | 0·0042 | 0·0649 | 16 | 0·141 | 9·149219 |
| 10 | 0·0040 | 0·0634 | 18 | 0·126 | 9·100371 |
| 12 | 0·0037 | 0·0610 | 20 | 0·114 | 9·056905 |
| 14 | 0·0035 | 0·0590 | 22 | 0·104 | 9·017033 |
| 16 | 0·0033 | 0·0573 | 24 | 0·096 | 8·982271 |
| 18 | 0·0031 | 0·0558 | 26 | 0·089 | 8·949390 |
| 20 | 0·0029 | 0·0544 | 28 | 0·083 | 8·919078 |
| 30 | 0·0024 | 0·0494 | 30 | 0·078 | 8·892095 |
| 50 | 0·0019 | 0·0437 | 50 | 0·047 | 8·672098 |
| 100 | 0·0013 | 0·0369 | 100 | 0·024 | 8·380211 |

The symbols in Humphrey and Abbot's Mississippi Report corresponding to those in Dupuit's and Bazin's works, are as follows :—

| Humphrey and Abbot's | | | | Dupuit's | | Bazin's | |
|---|---|---|---|---|---|---|---|
| $s$ | in Humphrey and Abbot's | represents | $i$ | in Dupuit's | I | in Bazin's | |
| $a$ | ,, | ,, | ,, | $\Omega$ | ,, | $\omega$ | ,, |
| $p$ | ,, | ,, | ,, | $\chi$ | ,, | $\chi$ | ,, |
| $r$ | ,, | ,, | ,, | R | ,, | R | ,, |
| Q | ,, | ,, | ,, | Q | ,, | Q | ,, |
| $v$ | ,, | ,, | ,, | U | ,, | U | ,, |
| V | ,, | ,, | ,, | $v$ | ,, | $v$ | ,, |
| Vo | ,, | ,, | ,, | V | ,, | V | ,, |
| $V_1$ | ,, | ,, | ,, | W | ,, | W | ,, |
| $d$ | ,, | ,, | ,, | $z$ | ,, | $h$ | ,, |
| D | ,, | ,, | ,, | H | ,, | H | ,, |
| W | ,, | ,, | ,, | L | ,, | L | ,, |

Bazin's formula for the mean velocity expressed in English feet is

$$v = r\sqrt{\frac{1000\ s}{0{\cdot}08534\ r + 0{\cdot}35}}$$

J. M. H.

# No. CCLXXVI.

## FORMATION OF EMBANKMENTS BY SILTING.

*An examination into the system of making Embankments by the Silting Process, as performed on the Neilgherries, by* W. G. McIvor, Esq., *with suggestions for its improved and extended application.* By Major W. E. Marshall, *Exec. Engineer, P. W. Department.*

*Definition of the "Silting Process."*—The essentially novel feature in the method employed by Mr. McIvor of constructing embankments, is the utilization of the "silting process;" by means of which water is made to perform a large portion of the excavation of material, and to become the agent for its carriage to, and distribution at, site.

*Conditions deciding the site of work.*—No reason is apparent that should cause engineers, in considering circumstances which ordinarily lead to the determination of the size, form and general position of an enbankment, to deviate from the rules that would guide them were it to be made by the ordinary processes. But the following indispensable conditions would necessarily decide their judgment in fixing the *site* it would actually occupy.

I.—That there be rising ground on one or both ends of the site, covered with a sufficient quantity of suitable clay, situated higher than the proposed embankment.

II.—That there exist the means of conducting at small cost, an adequate supply of water to the whole of the approved material.

*Design of embankments by ordinary processes.*—In an earthen dam for the purpose of retaining a large body of water, made by ordinary (dig-

ging and carrying) processes, the engineer considers himself fortunate to be enabled to construct it entirely of clay. And, where circumstances oppose his doing so, he usually designs his embankment to contain a core of material which he can rely on, as being impervious to water, *i. e.*, a wall of puddled clay.

*Difference between the silting and ordinary processes.*—In forming a retaining embankment by the "silting process," it happens that precisely the same motives operate and the same remedy is applied: water instead of man being the chief agent employed; in which consists the sole difference between the two systems.

*Advantages of clay in the silting process.*—In the "silting process" however, the advantages of clay—disintegrated Granite, Gneiss and Hornblende—over other soils, are superlatively great. It has the property of breaking up quickly under the action of water in brisk motion (specially so if not very pure) and dissolving thoroughly in the running stream. It is thus readily and with great facility disseminated by means of water, and when it reaches the site, spreads evenly; forming a sediment of extreme closeness and tenacity.

## The Silting Process.

*Water to be led from neighbouring springs to clay grounds.*—The first thing to be done, is to conduct along the hill sides, from neighbouring springs and perennial water-courses, to the highest level of the clay ground, one or more streams; dependent in number and cubic content on various contingencies; for instance, in proportion to the importance of the undertaking (the amount of work to be done in a given time)—the number of clay grounds—the consistency of the soil, &c.

*Utilization of water with greatest effect in channels.*—When the water has been brought to the head of the ground where it is proposed to excavate, it should be led in channels down the very steepest slope of the hill, in the general direction of the projected work: this, with the object of utilizing the water with the greatest mechanical effect—weight into velocity.

*Size of water channels.*—These channels should not be too large, for fear they should become unmanageable. Though no precise size can be prescribed for them, experience would tend to show that a discharge of

a cubic foot per second each, forms a handy volume of water, and one that may readily be kept laden with silt.

*Soil tilted into water.*—Coolies are now stationed at intervals on either side of these channels, who with three or four-pronged forks, such as are commonly used in digging potatoes, or with pickaxes, loosen and tilt the soil of their beds and banks into the flowing water.

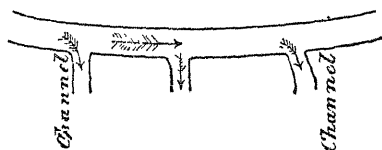
*Soil broken up by water.*—Thus, in the progress of work, the channels both widen and deepen, until they form chasms many feet wide and deep; into and through which the water dashes in cataracts; breaking up, disintegrating and dissolving the soil thrown into it, on its way down towards the works.

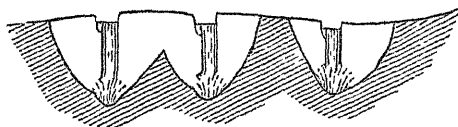
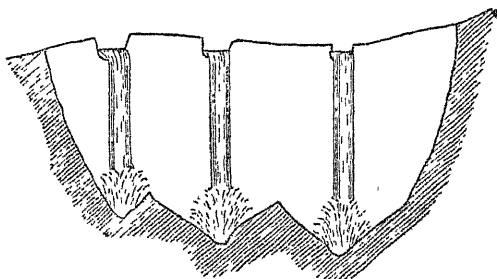
*Clay grounds to be high up and distant from embankment.*—The greater the distance of the clay grounds from the site of the embankment, and the steeper the slope that the beds of these streams can be made to maintain throughout their passage, the more completely homogeneous will the silt be rendered by the time it reaches its destination, and the larger will be the volume of solids in proportion to water, that can be borne down by the current.

*The proportion of silt to water.*—Experience, having reference to the nature and consistency of soil, and the available slope of land, will in each case dictate the proportion that silt may be allowed to bear to the water that carries it. For, whilst on the one hand, it is a matter of essential importance, to deposit the silt as free of liquid as possible; on the other, a point of solidity may be reached, when the silt, which, owing to superior gradients, reaches the required site with facility, may be too solid to spread itself: and hence manual assistance may be necessitated, which the "silting process" properly conducted, should at this stage of work, supersede.

*Mr. McIvor's device for adding to the efficiency of water.*—Doubtless, an extended experience will suggest many improvements for the purpose of increasing the efficiency of water as an excavator; wherefore, a device that Mr. McIvor has introduced on his works with this aim, may be suitably described in this place.

is, by penetrating the interstices, to soften and undermine it; causing it

*Plan of water channels in course of enlargement.*

*Section of Channels.*

*Appearance when the channels have been enlarged.*

*Appearance when the channels by enlargement have merged into one another*

without further assistance, to melt and slide down in flakes; when, by the further agency of the water, it is washed into the channel, and carried off.

Thus, work which by the ordinary process would have been performed laboriously and therefore in an expensive manner by means of coolies, is executed with great economy and ease by the water itself.

*Nature of substrata of clay.*—The sublying strata of clay (*in situ*, as it is usually met with in hilly districts, rather than in the form of alluvial deposit), which consists of the partially decomposed material that marks the course of its transition in decay from stone, are conspicuously made up of rotten stone and its sand, imbedded in very pure clay.

*The substrata of great value as material.*—Although this substance would not contain so much clay as the upper or fully developed stratum would do; yet the property of great toughness, and the power of cohesion it is well known to possess, show its fitness for use in retaining embankments.

*Cannot be worked by water alone.*—This hard material could not be acted on by water alone, with sufficient effect to admit of the stream loading itself with the mass of silt which has been already explained to be so desirable; and cooly labor could not be applied on it with the economy which it is the pride and aim of the "silting process" (taken in its entirety) to achieve.

*Occasions when gunpowder might be used.*—Without attempting to detract from the ascertained value of this system, it may be asserted that gunpowder could often be advantageously used both in the earlier stages of the work, in substitution of ordinary cooly labor, and at a more advanced period, to shake the mass of indurated clay, or to throw it into the water as the case might be, when it would be rapidly acted on by the stream, by being melted and carried off in it—the great aim being always borne in view, to keep the stream loaded with as much silt as it can conveniently be made to carry.

*Measures to retain the silt at site.*—In view to receiving the silt as it is brought down by the water channels from the clay grounds, the whole site of the embankment to be formed must be enclosed.

Where the ends of the work will rest on the natural support of the hill slopes, the other two sides alone would require artificial protection. A bank of earth sufficiently high and broad, should be formed to retain the liquid mud, and raised from time to time so as to maintain a command over the silt as it rises by daily deposit.

There are two modes of treating the silt as it is discharged into this basin; either of which may be adopted, according to the system it is desired to pursue.

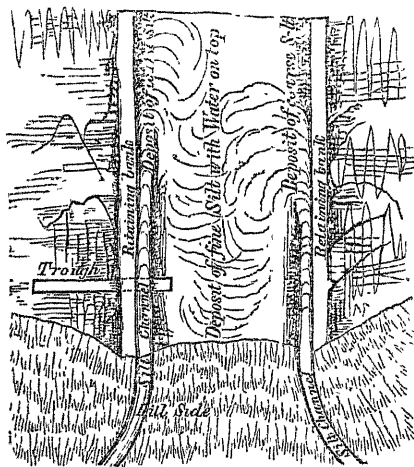
I.—Where the clay is of sufficiently good quality to warrant this construction of the entire dam with it, it may be used in its natural condition, or more correctly, in the homogeneous state in which it arrives at site.

II.—Where, from the material being highly mixed with sand or stone, it is of inferior nature, it is deemed advisable to construct the embankment with a core of clay so pure and dense as to be impervious to water.

*First method of treating silt.*—In the first case, the process is almost as simple as can be, viz., to allow the silt from every channel, to pour into the basin, with no further regard to detail or system, than keeping the directions of the streams divergent, so as not only to avoid causing whirlpools on the top of the work, which might lead to the occurrence of accidents, but to encourage slack or still water, into which the silt might at once settle—and that each day the tracks of these streams be made to vary their routes slightly, in order that the mass of deposit may be formed as free from faults and as uniform in quality as it is possible to make it.

In due course the silt which settles, leaves the pure water lying on the surface free from all deposit. It may then be drawn off continuously from one or more places, as experience and the circumstances of each case and of each day may dictate; by means of channels cut in the hill sides, or in wooden troughs leading beyond the limit of the earthwork.

*Second method of treating silt.*—In the second system, the object to be attained is the deposit of the dense coherent clay in the form of a puddle wall down the centre of the embankment, with the less adhesive, coarser, and more permeable material along its edges.

*Plan of the surface of portion of a Dam, showing the process of silting.*

This aim may be achieved as follows:—By guiding the contents of the laden channels, as they reach the site of the work, along its margins, whereby the action of mere gravity, the heavier particles of the silt are at once precipitated, whilst the lighter atoms (clay in fact) flow on. This deposit, by raising the edges of the embankment, has the effect by contrast, of forming a hollow all down the middle of its surface, into which the clay settles. The clear water is then led off in the manner before described.

By a judicious use of troughs, this process could no doubt be worked with as much nicety as could be desired. The heavy particles could be discharged at any spot selected along the edge of the embankment; and these places of deposit could be varied day by day; so that whilst in the centre of the work, the impervious clay would rise like a wall, with steady uniformity, the sides could be formed of homogeneous material, which, though coarse, would be heavy, and consistent from being cemented in a matrix of the clay which would be thrown down with it.

*More care required in second method than in first: results superior.*—This latter system requires more care and skill in working it than the first; and is therefore not only to some small extent, more expensive, but is one in which the progress cannot be forced in the same degree. For whereas in the former, the silt channels having once been duly directed, and the exit for the pure water provided for, the process may be allowed to go on day and night, without further assistance, restricted alone by the limit in thickness (probably about 1½ feet) to which soft clay may be deposited without losing shape, and therefore its cohesion and consistency; in the latter method of working, a few men must be kept employed to watch and guide the silt. The existence of a necessity for such care would also point to a difficulty in carrying on the work by night.

*Amount of silt with which water can be laden, not yet determined.*—The amount of silt that can be brought down from the clay grounds, in any given slope and volume of water, has not been satisfactorily determined. This should be done; and means adopted by which it may at any moment be ascertained on the work, if the silt is being delivered in the degree of consistency that has been tested and approved.

*Quality of the silt unexceptionable.*—An inspection of samples of silt formed by the processes which have been described, would satisfy the most scrupulous that nothing is left to be desired in its quality. It is greatly more homogeneous and compact than could be made by ordinary processes—and that homogeneity and compactness can be increased to almost any extent desired.

*Silting process gives better work than by ordinary methods.*—Provided that ordinary engineering precautions be taken for the safety of the work, there does not appear any reason why an embankment made by the 'silting process" should not be, *at least* as strong as one constructed by ordinary means.

*Cost of the silting process.*—As regards cost—the expenses incurred in the only operation of the kind that has been executed in India, not having been made known, information is wanted before a comparison between the working of the two systems can be reduced to figures.

A few observations bearing on this subject will not, however, be out of place here.

Dams for the retention of water being required solely in hilly districts; which, as a rule in India, oppose obstacles to the assembly and retention of large bodies of workpeople and cattle, and to the utilization of wheeled carriage or machinery, the agency of water at once presents itself as an admirable substitute. It has been shown how it can be utilized to excavate and break up soil; and, therefore, to reduce the amount and cost of human labor required in those items of the work to be done.

*Contingencies affecting the cost of water as a carrier.*—The carriage of clay when excavated, may be represented by the first outlay in making channels to conduct the water from the natural fountains down to the site of the work; the number, dimensions and cost of which, a perusal of the previous pages shows to depend on several contingencies, varying greatly with each case. They are much as follows:—

I.—The distance from the fountain head of each stream to the site of the embankment.

II.—The natural difficulties to be overcome in tracing the channels for these streams along the hill sides.

III. The amount of silt that the streams will carry in 24 hours.

IV. The amount of clay that may be deposited on the embankment in 24 hours.

*Economy of water in spreading and consolidating material.*—In the matter of spreading and consolidating material, an operation which ordinarily requires much labor, patience and supervision, it is performed by the water without additional charge beyond the work of five men per each discharging channel; who make and maintain the banks designed to retain and to guide the courses of the silt, and a few troughs, or short channels in the hill sides, by which to lead off the surface water.

*Reduced contingencies.*—The contingencies, which consist chiefly of tools and the huts for coolies, are small, in proportion to the lesser number of laborers employed.

*No charges for supervision or extras peculiar to the silting process.*— Such supervision and extras, as may be charged, are not peculiar to the "silting process."

*The principles of the silting process may be applied in many ways.*— In conclusion—as the operations which have been described in these pages, are in fact the working of a process by means of which water is made to perform three distinct operations, viz., the excavation, carriage and redeposit of material; all which are expressed in the general term "silting process;" a consideration of the principles involved may suggest many purposes to which it may be applied, and several methods by which it may by worked, according to the various combinations and applications of those operations.

OOTACAMUND,<br>*April*, 1870.

W. E. M.

## ADDENDUM TO No. CCLXIX.

## STEAM ROAD ROLLERS IN INDIA.

*(Arrived too late for insertion in the body of the article.)*

*Memorandum from* W. CLARK, ESQ., *Engineer to the Justices of Calcutta, to the Secretary to the Justices.*—Dated the 16th February 1870.

The engine is capable of rolling *per day* * 1,000 lineal feet of road metal, 10 yards wide, going over it three times.

The layer should be about 4 inches thick, and *thoroughly soaked* with water.

The cost of a day's work for fuel and establishment will be about Rs. 16 per day, exclusive of repairs, or with repairs estimated at Rs. 100 per mensem, Rs. 20 per day.

The Calcutta roller has *never yet approached this amount of work, nor one-half of it.* The reason for this is that it never has actually travelled more than about 4 miles; it should travel 11 or 12 miles; the fact being that sufficient extent of layer, and the quantity of water absolutely necessary have never yet, so far as I know, been provided, and it costs nearly as much for the machine to stand still under steam as to roll.

The French road roller which I purchased on behalf of the Justices, has the merit of being lighter than any of the other rollers, (the Justices first roller excepted,) and it also has the advantage of being on springs; these features induced me to select it in preference to any others which have been made. I consider, however, that it is too expensive a machine, and some of its parts are liable to get out of order sooner than such a machine should do. The rollers by Messrs. Aveling are not on springs, and are too heavy, unnecessarily so, for the purpose for which they are intended.

* Six hours, the usual time for drivers.

I am informed that a roller is being made by Mr. Batho, 36 Lancaster Street, Birmingham, for the authorities of that town, which is probably finished by this time, and which is intended to overcome many objections to other road rollers already made, and will be a great improvement on Aveling's, the principle of which is copied from the first steam road roller made for the Justices, and which is deficient only in boiler power.

*Memorandum.*

| | RS. | A. | P. |
|---|---|---|---|
| Cost of stream road roller, .. .. .. | 16,297 | 11 | 8 |
| The cost of establishment, &c, per mensem— | | | |
| For working the roller, .. .. .. .. | 212 | 0 | 0 |
| Coals, .. .. .. .. .. .. | 144 | 0 | 0 |
| Stores, .. .. .. .. .. .. | 24 | 0 | 0 |
| Total per mensem, .. | 380 | 0 | 0 |

exclusive of any repairs.

*Memo by* W. Clark, Esq., *Engineer to the Justices, of Calcutta.*—9, Victoria Chambers, Westminster, S. W.—Dated 24th July 1868.

I have inspected the steam road rollers which are in use in Paris, Sheffield and Liverpool. A roller similar to the one sent to Bombay has been manufactured for the Government for rolling the roads in Hyde Park, and after waiting for several weeks, I am now informed that I am not likely to have an opportunity of seeing it in operation for some weeks to come. I therefore cannot longer delay my report on this matter.

The steam road roller sent to Calcutta in 1864 was the first ever constructed in this or any other country; it was illustrated in the *Engineer* Newspaper in 1864. The next in order of date was the Paris road roller. This machine is the property of a Company who inform me they commenced to experiment in July 1864; their contract with the Paris Municipality for rolling the roads of that city was made in August 1865, and they were allowed to the beginning of 1866 to prepare seven machines, that being the number which the contract required they should have on commencing to work; since that time the rolling of the macadamized streets of Paris has been continuously in operation; they have thus had two and a half years of experience, and have added several to the number of ma-

chines; and considerable modifications and improvements have been made.

They have engines of three different weights, the lighter one being 14 tons 5 cwt. empty, another 23 tons, and a third 29½ tons. They prefer to use the lighter engine for commencing the work, and a heavier one after having obtained a smooth surface. The above engine when loaded with water and coke and ready for use weighs 2½ to 3½ tons heavier than above stated. The Company is paid by the weight carried over a given area of ground, and this amounts to 8*d.* per ton per mile at night, and 10 per cent. less in the day time. This rate is said to be fairly remunerative to the Company, who keep up an establishment of engines with shops, men, material and machinery, exclusively for their repair and construction.

The machines consist of a horizontal multitubular boiler carried by the *two* rollers and mounted on springs, so arranged that fresh surface plates can be supplied as the old ones are worn out.

The rollers are both driven by pitch chains worked by the engine which is fixed on the boiler.

The steering is effected by an arrangement which alters the distance of the centres of the rollers at one end, the other or driven end remaining fixed; with this arrangement the machine can be turned in a radius of 40 feet. The entire weight of the machine when loaded, say 17 tons, is thus supported on a length of 4 feet 11 inches × 2 feet = 9 feet 10 inches, or about 1·7 tons per foot in length; the engine is said to be an effective 18 horse-power. The pitch chains, driving pinions, shafting, piston rods, &c., &c., are of steel, the fire box of copper; the quality and style of workmanship is guaranteed to be equal to the best *locomotive* work in England. The machine, as I saw it at work, travels at about 3½ miles per hour over a layer of flint stones from 3 inches at side to 7 inches thick in the middle; the metal was watered from the street mains, and *two* engines commencing at the side, travelled over a length of about 300 feet backwards and forwards; there was not the slightest difficulty or hesitation in reversing the motion, nor was there any indication whatever that the metal was *driven* or *pushed up before the rollers.* Binding materials, consisting of *road scrapings*, were put on after the *rollers* had been over it several times. The usual plan is to work during the night between midnight and 7 in the morning, over a portion of road which may be at once opened to the ordinary traffic the following day, and the operation appeared to be perfect.

The Company admit that it is expensive to keep up the machines, which are kept *constantly* at *work*, and I should judge, from enquiries I made, that the repairs may be estimated at about 15 per cent. of the cost. The adoption of brass tubes in the boiler and copper fire boxes, &c., &c., on the locomotive pattern, ensure, a very considerable saving in fuel.

I left Paris with a very favorable impression of the machines I have briefly described.

The next machine in order of date is one in use at Liverpool.

The machines in use at Liverpool and Sheffield are by the same makers, Messrs. Aveling and Porter, and are similar to the Calcutta roller, having one front steering roller and two driving rollers, but with horizontal boilers.

The Liverpool machine has been in use about twelve months; it was under repair and had been out of use for about a month. The driving pinion, which was of cast-iron, had been broken and was being replaced by a wrought-iron one. I found that a similar failure had occurred to the one at Sheffield; this, however, I saw in operation; it has been in use about four months.

The Liverpool machine weighs 30 tons when empty, and is 9 feet 5 inches wide; the one at Sheffield weighs 25 tons and is 7 feet 6 inches wide. I rode on the Sheffield machine to its work; it was steered with great facility, and by uncoupling a wheel, could be made to turn in its own length; it was made to travel over a new layer of broken slag (from iron furnaces) which had been soaked in tar, and did its work very efficiently. I noticed, however, that the *front* roller appeared to *drive* up the metal in *front* of it—it appeared to rise like a wave. This I have no doubt is due to the fact of the front roller being *pushed* forward and not *driven* by the pitch chains and engine. I do not notice this as any serious defect, but there can be no doubt that to some extent it *disturbs* the metal and offers an extra resistance to the passage of the roller, causing a somewhat extra consumption of fuel. In conversation with the mechanics who drive the machines, I found that they both consider them *too* heavy and the power of the engine too small, and in this I agreed with them; they said also that unless metal be soaked with water, there is a difficulty in getting the roller over it. At Liverpool, besides watering, they cover it with about 1 inch of sand before sending the roller over it to obviate this difficulty. It is but justice to the

makers however to say that the Borough Engineer of Liverpool, Mr. Newlands, a very old friend of mine, and also the Surveyor of Sheffield, speak very highly of the machines, and are well satisfied with them.

The style and make of the engine is that of good *portable* engines, such as the makers are celebrated for. The boiler tubes and fire boxes are of wrought-iron, and most of the parts which are steel in the Paris roller are here of wrought-iron.

I may mention also the absence of springs in these machines; the drivers both considered the shaking and concussion to which they are subject make it necessary to have them on springs. The makers, however, object to this, as they would introduce some complication and extra expense, and they consider the frame sufficiently strong to bear all the strains to which they are subjected without danger of injury. The drivers, as I have said, do not agree in this opinion, and they told me in some places extra bolts had to be added.

The Paris makers tender to make a machine weighing 14 tons 5 cwt. empty, or 17 tons when loaded with double cylinder engine of 18 horse-power, for £1,120. A similar one, but weighing 22 tons empty, for £1,800.

Messrs. Aveling and Porter's prices are as follows :—

| No. | | weighing | | feet length of Roller | H. P. | Diameter and length of cylinders. | | |
|---|---|---|---|---|---|---|---|---|
| No. 1 | weighing | 15 tons | 6 | feet length of Roller | 6 | 7¾″ | × 10 | £ 500 |
| „ 2 | „ | 20 „ | 6-8 | „ „ | 8 | 9 | „ 12 | „ 600 |
| „ 3 | „ | 25 „ | 7-6 | „ „ | 10 | 10 | „ 12 | „ 750 |
| „ 4 | „ | 30 „ | 8-9 | „ „ | 12 | 11 | „ 14 | „ 900 |

Messrs. Moreland and Co.'s letter (copy annexed) speaks of their engine, and I cannot further remark upon it until I have seen it in operation.

All the makers decline to guarantee machines after arrival in India, but offer to give any reasonable proof of its efficiency before despatch. Under these circumstances, I am unable, under the instructions contained in the Secretary's letter of 27th April, to order a machine from any one of the makers, but the opinion I have formed would lead me to prefer the Paris machine at £1,120. I consider its extra power, its having *both* wheels driven, its being on springs, and its generally higher class of work, both in material and finish, coupled with the *extra* experience of the manufacturers in the use of these machines, make it worth the extra expenditure.

At the same time I must say I consider it to be a high priced machine, and that of Aveling and Porter's exceedingly moderate. I may also observe the Paris machine with its extra power admits of being made heavier when required, by the simple expedient of loading it with pig iron.

The Paris makers would undertake to use the machine on the Paris roads for any time that might be deemed desirable before despatch, so as to prove its efficiency.

I may here remark, that it has been found in Sheffield that one of the uses to which the machines can be advantageously applied is to loosen the road surfaces before the new layer of metal is put on them; this is done by a set of spiked plates which can be fixed on the rollers, by which a series of four rows of steel spikes about 9 inches apart, 2 inches long, are driven into the surface. These spikes can be applied to any of the machines.

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*From* MESSRS. R. MORELAND AND SONS, *to* W. CLARK, ESQ., C.E.—Dated 3, Old Street, London, E.C., the 8th June, 1868.

SIR,—With reference to your advertisement in the *Engineer* of the 29th May, we beg to hand you herewith copy of the *Engineer* Newspaper of 1st November, 1867, in which you will find a drawing and description of our road roller, and we enclose a small photograph showing its external appearance.

We now make the cylindrical part of the roller of cast-iron (in two parts for convenience of shipment) with wrought-iron plate ends and diaphragm.

Springs are fitted both over the rollers and steering wheels, and support the whole weight of the framing and machinery.

Our rollers have been designed and constructed in all parts with a special view to secure the greatest efficiency and durability, and we invite particular attention to these advantages.

*1st.*—The great diameter of the roller secures the best work with least amount of power.

*2nd.*—The vertical boiler is a great element of safety when working on steep inclinations; as in such cases, the water to a great extent leaves one end of the ordinary locomotive boiler, and to this cause was attributed the bursting of a Paris steam roller.

*3rd.*—There is no gearing to cause noise and increase wear and tear.

*4th.*—All the machinery being covered, is protected from dirt and injury, and nothing is to be seen to frighten horses.

In proof of the superiority of this roller we may state that after the roller described in the *Engineer* was tried in Hyde Park last year, the Government dispensed with a roller previously on hire there, and gave us an order for a new one, which now does the work required in the Park.

We can supply rollers made on this general plan of construction, in two sizes at the following prices:—

| | | | |
|---|---|---|---|
| 26 ton roller | diameter of roller 7 feet 6 inches | £1,050 | 0 0 |
| | length 6 „ | | |
| 17 „ „ | „ „ 6 „ | £800 | 0 0 |
| | „ 6 „ | | |

These prices are for the rollers tested in steam and delivered in London. Packing and delivery *f. o. b.* in the Thames, costs 5 per cent. extra.

If on examination, you think proper to entertain our proposals for supplying a steam roller, we shall be happy to enter into any further details or modifications you think desirable, and in compliance with the requisition of the advertisement, we beg to refer you to the Government roller stationed in Hyde Park, which can be seen any day by previous appointment with us, as it is in our charge.

We invite a full trial of the machine, before leaving this country, and undertake to rectify whatever may be defective to your satisfaction; but we cannot assume any responsibility for its performance after it passes out of our control and is worked at Calcutta.

Terms cash, less 5 per cent.; one-half on the roller being satisfactorily tested under steam, and the remainder on delivery.

## APPENDIX C.

*From* A. CRAWFORD, ESQ., *Municipal Commissioner for the City of Bombay, to* R. TURNBULL, ESQ., *Secretary to the Justices of the Peace.*—dated 31st August, 1868).

As to the Steam Roller, I beg to annex copy of my Executive Engineer's Report.

I beg to add my testimony. The roller is a very great success and saves largely in the repairs of the principal roads. It is remarkably manageable, and can be steered or stopped by one man without the least difficulty. It is worked with the ordinary traffic running by it, and we have had no accident hitherto.

I have lately been especially struck with its work in comparison with the repairs with common rollers. We have two long main thoroughfares, the Breach Candy or Girgaum road and the Parell road, the traffic on the latter being greater than on the former. Both roads have been full metalled simultaneously. The Girgaum road is very rotten below, and will not bear the steam roller—the Parell road will bear it. The Girgaum road traffic is seriously inconvenienced by the heavy metalling, and the struggling bullock rollers, and it will take about six weeks to metal and consolidate it throughout.

The Parell road has been thoroughly metalled and finished in about eight days work in the following way:—A gang of 100 men with carts, &c., were put on to pick up, and prepare and spread metal and binding, over a half mile run, to half the width of the road. The steam roller would go on next morning and finish the whole off well in that day. It was then off to another part of the town for a day, while another run was prepared for it on the Parell road, and so on: it finds out every soft spot in a road. It is very easy taken up if it sinks.

I strongly advise your getting one of 15 to 20 tons.

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MEMO. *by* R. AITKEN, ESQ., *Exec. Engineer, Municipality.*

The steam roller supplied to us by Messrs. Moreland and Co., (Thompson's patent,) has more than answered the most sanguine expectations I had formed of it.

Viewed simply as a machine for forcing down road metal on roads which have been properly constructed originally, nothing can be more satisfactory; but as it is very heavy, it is rather too much for some of our roads, which not being properly bottomed give way under it, so that the roller sinks into them where there are weak places, and it takes some time to get it out again.

The expense of keeping it working for one month is as under:—

| | RS. | A. | P. |
|---|---|---|---|
| One European driver, .. .. .. .. | 120 | 0 | 0 |
| One Native fire-man, .. .. .. .. | 30 | 0 | 0 |
| Two lascars, .. .. .. .. .. .. | 30 | 0 | 0 |
| Coals for 25 days at 10 cwt. per day, 12½ tons at Rs. 25 per ton, .. .. .. .. .. | 312 | 8 | 0 |
| Oil wash, &c., &c., .. .. .. .. .. | 50 | 0 | 0 |
| Total Rupees,.. | 542 | 0 | 0 |

Say Rupees 550 per month.

One roller drawn by three pair of bullocks costs Rupees 5-4 per day, present rates, so that for one month of 25 working days the cost is at the rate of Rupees 131-4; or the steam roller costs only as much to maintain as four large rollers drawn by bullocks, whilst I believe it would do the work of ten rollers drawn by bullocks, and do it much more effectually, and with less hindrance to traffic.

At first, spirited horses were frightened by it, but now they are becoming quite used to it and take no notice of it.

A roller weighing, say 20 tons altogether, would suit our roads better than the one we have, but for roads which are well made, the present pattern weighing about 30 tons is, I think, about as efficient a tool as can be devised.

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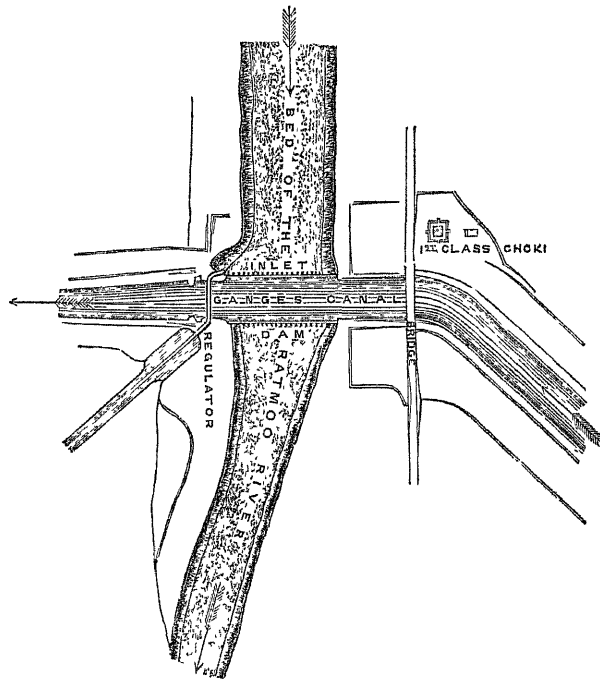
# No. CCLXXVII.

## THE DHUNOWREE WORKS—GANGES CANAL.

These works are situated about 13 miles below the head of the Canal, at its intersection with the Rutmoo river, which it meets on its own level; and the sills of the different works are therefore on the level of the Canal bed.

The Rutmoo, with the exception of a short period of the dry weather,

immediately before the annual rains set in, may be considered a perennial stream, though carrying a very small body of water. The area of the catchment basin is 126 square miles; its extreme length being 21 miles,

of which the upper six are mountainous, and the remainder jungle and forest; its average width is 6 miles, with a slope of bed in the neighbourhood of the works of 8 feet per mile.

The works, designed for the passage of this river across the Canal, consist of an Inlet on the right, and a Dam on the left bank, connected by revetment walls with an ordinary bridge of communication on the up, and with a Regulating bridge on the down, stream side of the Canal.

The Inlet was merely intended to confine the Canal water within its own limits and is now not used; the Dam, however, consists of 47 sluices of 10 feet in width, with their sills flush with the Canal and separated by piers 3½ feet wide; these are flanked on each side by 5 other sluices of the same width but having their sills raised 6 feet, with intermediate piers of the same dimensions as those already described; on the extreme flanks, are platforms raised to a height of 10 feet above the Canal bed, corresponding in height with the rest of the piers. The amount of water-way, therefore, through the sluices, up to a height of 6 feet, is equal to 470 feet in width; to a height from 6 to 10 feet it is increased to 570 feet, and when flood water rises above that height, it passes over the full expanse of masonry, which is equal in width to 800 feet. The sluices are fitted with gates which are held up by chains so as to confine the Canal water within its bed; these chains are very ingeniously fastened, so that on the occurrence of a flood, they can be released immediately by a very slight tap with a hammer.

The Regulating bridge consists of 10 bays of 20 feet in width each, fitted with drop gates, and the necessary apparatus for raising and lowering them.

On the occurrence of a flood, the mode of operation is as follows—the dam sluices are immediately opened, and the drop gates of the regulating bridge closed, by which means the flood is forced through the dam and down the bed of the Rutmoo; as soon as the flood has passed, the regulating bridge is again opened, and the dam sluices closed, which allows the Canal supply to run in its ordinary channel. For the purpose of working these gates, a considerable establishment is kept up at this point, whose duty is very heavy during the rainy season, as it is of the utmost importance that the gates should be worked with the greatest expedition, when floods are of frequent occurrence at all hours of the day or night.

The cost of these works was about £52,600.

T. G.

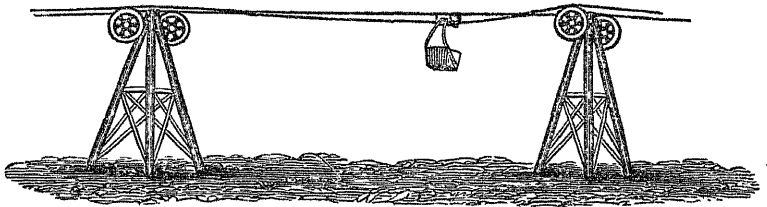
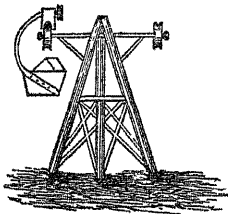
# No. CCLXXVIII.

## HODGSON'S PATENT WIRE TRAMWAY.

*Memo. by* CAPT. F. D. M. BROWN, V.C., *Assist. Principal, Thomason College.—On Furlough.*

THE wire tramway patented by Mr. Hodgson, 21 Gresham-street, Old Jewry, London, appears a most valuable and cheap method of opening out a new country; it seems especially applicable to India, where long continued rains and large rivers make country roads impassable for several months in the year, and where the construction of a metalled and bridged road has often to be delayed indefinitely for want of funds.

The plan consists of an endless wire rope, supported at intervals on fram-

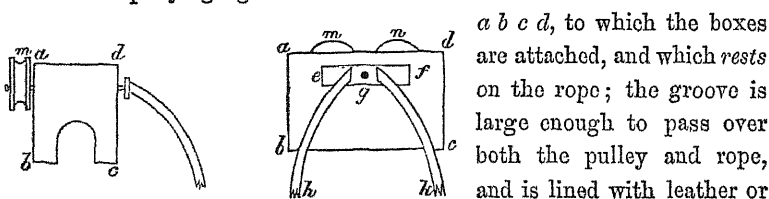
ed poles, each supplied with two arms carrying pullies, over which the forward and return ropes pass, being worked round two drums by a stationary engine.

The line crosses the country like a telegraph line and can be put up with great ease and rapidity; where the country has been sufficiently developed for a railway, the line can be removed and used elsewhere. In mountainous districts, by keeping near the rivers, a wire tramway might be most advantageously worked by water power at

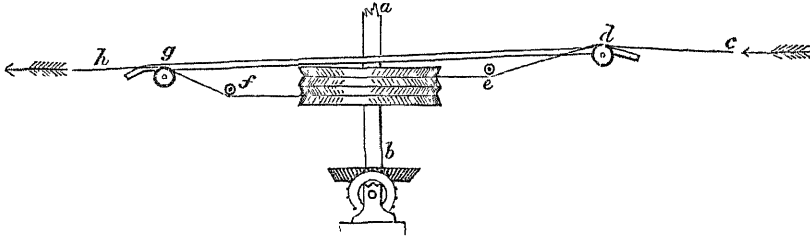
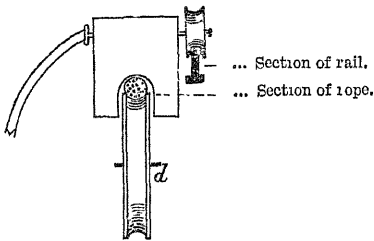
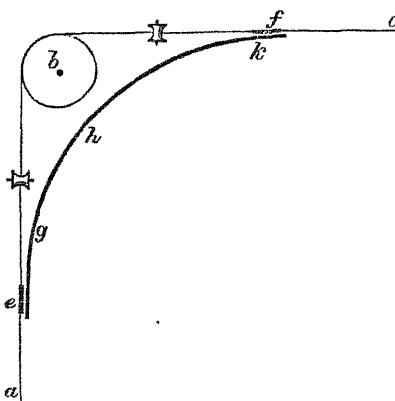
a very reduced rate. It might also be applied to landing and shipping goods from vessels in road-steads, applying water power to distant points, and numberless other purposes; but it is as a means of conveyance for goods that it is here described.

The longest distance between the drums should not exceed $4\frac{1}{2}$ miles; the posts are ordinarily placed at intervals of about 300 feet; but spans amounting to 1000 feet may sometimes be taken.

A box carrying the load is hung to the rope by a grooved block to which the box is suspended by curved iron bars, fixed to one side only, and so arranged that the centre of gravity of the whole frame may be immediately under the rope.

Each box is said to carry from 1 cwt. to 10 cwts., and 200 boxes are delivered per hour. The size of the boxes and the weight they carry will of course depend on the strength of rope and power of the machinery.

The accompanying figures show a front and side elevation of the block *a b c d*, to which the boxes are attached, and which *rests* on the rope; the groove is large enough to pass over both the pulley and rope, and is lined with leather or Indian rubber, where much friction is required for steep gradients; *e f* is an iron plate attached to the wooden block, by a pin at *g*, about which it can turn freely; to this plate are fixed the curved bars *h*, *k*, which support the box; by this arrangement, the box always hangs vertically, while the block adapts itself to the gradient of the rope. A pair of wheels *m*, *n*, are attached to the block; they are used for carrying the box on rails from one set of drums to the other, also at curves in the line, and for running the boxes off the rope at a terminus.

Where the line is more than $4\frac{1}{2}$ miles long, and the boxes have to be transferred from the rope on one set of drums to that on the next set, it is done as follows:—*a b* is the vertical shaft driving a drum: the endless rope, *c d e*, passing round the upper drum, returns on the opposite side

*f g h* is a continuation of the line by another endless rope, which passing round the lower drum returns on its opposite side. Between the pulleys

*d* and *g* is a rail, placed as far from the side of the rope as the wheels in the block are from the groove. The box coming up *c*, passes over *d*, and the rope descending under the pulley *e*, leaves the box on the rail hanging by the wheels. The rail having a fall, from *d* to *g*, the box descends, by its own gravity, until the rail is below the next rope at *g*, when the block again rests, by the groove, on the rope, and is carried forward to the next drum. Should the box be required off the line at this point, it is run on to a side line by means of switches. There is a similar arrangement for the return line on the opposite side.

By an ingenious adaptation of this principle, the line is made to take any curve; the rope coming up from *a*, passes a drum *b*, and goes on in any required direction *c*: after passing the pulley *e*, the block is left on the inclined and curved rail *g h k*, down which it rolls until it is again dropped on the rope at *f*.

The block simply rests upon the rope; its own friction being sufficient to prevent it slipping on gradients of 1 in 6. The power required in drawing the weight up gradients and the slack rope

between the posts, is counterbalanced by the descending loads, so that little more power than simply what is necessary to turn the rope is wanted. One engine will work two endless ropes, and as the drums ought not to be placed more than 4½ miles apart, one engine will be required for every 9 miles. Should the rope even break, it has been found, from experience, only to drop between 2 or 3 posts on each side of the fractured part, when its own weight and friction on the ground keep the rest taut, so that repairs are easily effected.

The following is extracted from a description, by the Agent, of a 5 mile line erected at Brighton, being part of a 60 mile line in course of construction for Ceylon.

"The Brighton line is more than 5 miles long; there are 112 posts in the whole length; the rope is made of charcoal iron, and is 2 inches in circumference. The speed of the rope is 5 miles an hour; the power employed is one of Messrs. Robey and Co's 16 H. P. engines, and the plant has been partly made by that firm, and partly by Messrs. Eastons, Amos and Anderson. Some of the spans are between 600 and 900 feet in length, and some of the gradients as steep as 1 in 8.

"The line is capable of delivering 240 tons per day of 10 hours *i. e.*, 120 tons in each direction. It is intended to divide the proposed line in Ceylon into 5 mile sections, such as this; one engine working two sections, and the boxes passing by shunting arrangements, similar to those used at these termini from one section to another."

On the next page is a price list given in the same pamphlet.

"The cost of erecting these lines in England is about 15 per cent. on those quoted, adding, for foreign lines, 15 per cent. also on the freight, and carriage to the spot.

"Sharp curves are charged extra.

"The prices include all plant necessary for delivering the quantity of goods specified, also the frame or platform of wood forming the support for the terminal drums and gearing; but any special arrangements rendered necessary by local requirements are to be provided by the purchaser, or charged extra.

"These estimates assume that the loads are to be all one way; at an increase of about 10 per cent. in price, the quantities named can be delivered both up and down the line.

| Line capable of carrying. | No. 1 50 tons a day in ½ cwt. boxes. | No 2 100 tons a day in 1 cwt. boxes. | No. 3 200 tons a day in 2 cwt. boxes. | No. 4 350 tons a day in 3 cwt. boxes. | No 5 500 tons a day in 4 cwt. boxes. | No. 6 1000 tons a day in 6 cwt. boxes. |
|---|---|---|---|---|---|---|
| | £. | £. | £. | £. | £. | £. |
| Line with framed wood posts, wrought-iron tops and patent pulleys, best charcoal iron wire rope, and steam power, consisting of self contained engine and boiler ready for work, free on board or delivered in England, per mile, | 200 | 300 | 500 | 700 | 1000 | 1500 |
| Add for a pair of terminals on any length of line up to five miles, | 100 | 150 | 200 | 270 | 380 | 500 |
| Rolling stock of wood and iron, per mile, | 40 | 70 | 120 | 200 | 300 | 400 |
| Rolling stock all of wrought-iron, per mile, | 55 | 90 | 150 | 240 | 360 | 480 |
| Extra for best steel wire rope, per mile, | 40 | 80 | 140 | 200 | 280 | 400 |
| Extra for iron in place of wood posts, per mile, | 35 | 40 | 50 | 80 | 130 | 200 |

Taking, from this list of prices, one-fifth of the cost for terminals and adding the extra for iron rolling stock, best steel wire and iron posts (which would be necessary in India); also 15 per cent. for freight, 15 per cent. for erection and 10 per cent. on the whole for carriage of goods both ways, the totals of the respective columns, including engines, plant and terminals, set up and in working order in India, would amount per mile to

| No. 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| £. | £. | £. | £. | £. | £. |
| 500 | 772 | 1288 | 1821 | 2639 | 3832 |

Short lines of this construction have been erected at several places, and are said to give great satisfaction. They can only be supposed to act as feeders when large quantities of goods in small parcels of a few cwt. each have to be delivered and when time is no object, as the speed is only from 4 to 5 miles an hour.

F. D. M. B.

*London, May* 1870.

# No. CCLXXIX.

## BRAKE POWER ON RAILWAY INCLINES.

*Report on experiments lately made at Bombay for determining the necessary Brake Power required on the Bhore Ghât Incline.* BY CAPT. T. H. WHITE, R.E.

TO THE CONSULTING ENGINEER FOR RAILWAYS.

*Bombay, February, 1870.*

SIR,—I have the honor to submit herewith the result of the experiments* that I have carried out on the Bhore Ghât, in accordance with Government Resolution, of the 4th October, 1869, in order to determine the co-efficient of friction of brake-power in the working of the Incline.

The greater number of the experiments were made on the upper portion of the Incline, on the gradients of 1 in 40 and 1 in 50, between Lanowlee and Khandalla. As the distance between these two stations is only two miles, but a very short section of the line was blocked to traffic while the experiments were going on, and Lanowlee being the head-quarters of the Traffic and Locomotive Departments of the Ghât section, men and materials were always ready at hand, and we were thus enabled to avail ourselves to the full of the two or three hours' possession of the Line accorded to us by the traffic in the early morning. The Assistant Locomotive Superintendent of Lanowlee, Mr. Bell, was present at nearly all the experiments, and my best thanks are due to him for the great assistance he has given me, and the ready manner in which he worked with me throughout.

* It has not been thought necessary to print the experiments in detail here—this Report gives the practical results.—[ED.]

*Plan of Incline.*—A plan and section of the Ghât are annexed;* it will be seen that the road at the head of the Incline is straight for the first 814 yards; there is then 308 yards of curve of 80 chains' radius, then 462 yards of straight, then 286 yards of a 40-chain curve, then 286 yards of straight, and after this an S curve of 40 and 30 chains' radius, which reaches nearly to Khandalla station; it will be allowed, I think, that for all practical purposes the line may be considered straight for the first 1,584 yards (or seven-eighths of a mile) at the head of the Incline.

In the larger number of instances, the rolling friction has been determined from the experiments made on the straight line; it hardly appeared to me necessary to take into consideration the resistance of the curves, as I found in actual practice, from a few experiments made on the curves of 40 and 30 chains' radius, that the increase of friction was not appreciable; the difference of the co-efficient of friction on the same morning, running with the same vehicles and over the same straight section of the line, was often greater than would be caused by any but a sharp curve. The influence of the curve was, in fact, only felt when the vehicle was running at a very low velocity, that is, when it was on the point of stopping.

It is to be remarked also that the accuracy of the experiments was scarcely, if at all, affected by the varying force of the wind; for the upper portion of the Incline is singularly free from those violent currents which are so prevalent at this time of the year at Khandalla and the Reversing Station. Whatever breeze there was, was in favor of the vehicle, increasing its velocity, and thus slightly diminishing the deduced friction.

*Manner of carrying out experiments.*—The experiments were carried out in the following manner:—

The vehicle or vehicles were allowed to descend the Incline by gravity for a certain measured distance; at the end of this length, fog-signals were placed at an interval of 66 and 44 yards (they were first placed at a distance of 66 yards, but as the increase of velocity was decidedly observable in running over this length, I reduced the interval to 44 yards); the velocity between the fog-signals, which was accurately registered by chronographs, was considered as the final velocity. On reaching the 2nd fog-signal, the brakes were instantaneously applied, and the vehicle or

* *See* Vol. I. of these Papers.

vehicles were brought to a stand in a certain distance; this distance having been measured, the vehicles were hauled up the Incline by an engine, and the experiment was then repeated at any required velocity.

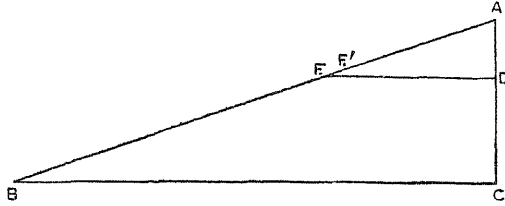
As a rule, the experiments were carried out at what may be considered high velocities for the Ghâts; *i. e.*, at speeds varying from 15 to 40 miles an hour; there appeared to me no necessity for working either at low velocities or with heavy loads. In the former case, in an *ordinary* condition of the rail, if Ghât rules are adhered to, and there is a proper provision of dry sand, the Incline may be considered safe; in the latter, there would have been great delay in carrying out the experiments, and with no corresponding results; the brake-power must be always proportionate to the load, and whatever proportion is found necessary for a train of 30 tons descending the Incline, a corresponding proportion will always be required for a train of 200 tons, supposing both trains to descend the incline under similar circumstances.

The action of the brakes, both skidding and not skidding, was tested over a rail in every *possible* condition. Though I was most unfortunate in not being able to test the effects of a heavy dew, a considerable number of experiments were made in the early morning when there was a slight dampness on the rail, and the result of these has alone been quite sufficient to show what a dangerous element dew is in the working of early morning trains in the cold season of the year.

A very heavy dew may perhaps be represented by an oiled rail, though not to such an exaggerated extent as many would consider. I am, in fact, rather doubtful whether the effects of the former can be *much* exaggerated; one or two experiments will hereafter be alluded to regarding this point—at first cocoa-nut oil was employed for lubricating the rail, but as this congealed and was difficult to lay on, it was found better to use castor-oil, which has, I believe, higher lubricating powers. The rail was also treated with soap, but this dried up too soon, and then became sticky, so that the skidded wheel running over it gave but little, if any, difference of result from that of the dry rail.

The vehicles experimented on were generally Ghât brakes, open at both ends, opposing little resistance to the wind, and of an average weight of about 10 tons. Brake W, which was used oftener than the others, was provided, in addition to the ordinary brake, with a heavy lever, working on to 4 brake-blocks, which, when allowed to fall, skidded the wheels

immediately, and thus secured a greater amount of accuracy in calculating the length run with skidded wheels, after passing the second fog-signal.

*Method of calculating friction.*—The manner in which the co-efficients of friction and adhesion of brakes have been worked out may be stated, though I have only followed ordinary mathematical principles.

If a body falls down an inclined plane A F B, were there no friction, it would attain a velocity at a point F due to the height A D $= h$; but as motion is impeded by friction, it only attains a velocity due to a height which I will call $h'$; this loss in height, or the difference between $h$ and $h'$ divided by the length A F $= l$, gives the rolling friction, including the resistance of the air. Stated in other terms, if W be the weight and M the mass of the body, the work the body should accumulate at F without friction would be $W \times h$, but it only accumulates $W \times h'$. The work lost then is the work destroyed by friction ($f$) or

$$Wh - Wh' = M f l \text{ or } M f = \frac{h-h'}{l} W.$$

where $h' = \frac{v^2}{2g}$, $v$ being the velocity in feet per second shown by the fog-signals over the distance F F′ (44 yards).

When the vehicle runs skidded from F to B, where it is supposed to stop, motion is then entirely destroyed by friction ($f'$), which thus overcomes the work due to the height $h'$ + that due to the additional height D C $= h''$ or $Wh' + Wh'' = M'; f'^2 l'$; where F B $= l'$

$$M f' = \frac{h' + h''}{l'} W = \left(\frac{v^2}{2g\, l'} + \frac{h''}{l'}\right) W = \left(\frac{v^2}{2g\, l'} + \frac{1}{40}\right) W.$$

supposing that the brake was running on an incline of 1 in 40.

All the problems have been solved by these equations, and the results tested by the experiments, which were afterwards carried out in the catch-siding. These will be compared hereafter.

*Experiments with Ghât lorry. Skidding and not skidding.*—As some

alterations were being carried out on brake W, I commenced the experiments by trying the different effects of skidding and not skidding on a Ghât lorry. This lorry weighed altogether with its load 1,712 lbs. was in good running order, and was provided with 2 brakes, which allowed of the brake-power being applied to a nicety. The result was as follows :—

Running at a velocity of 26·4 miles per hour on the incline of 1 in 40 the lorry was pulled up on a dry rail when the wheels were *skidded*, in 87 yards, and the adhesion worked out $\frac{1}{8 \cdot 6}$; running at the slightly lower velocity of 25·6 miles per hour, it was pulled up *without skidding* the wheels, in 56 yards, and the adhesion was as much as $\frac{1}{6 \cdot 4}$.

Experiments were afterwards made with an incline brake, which gave somewhat the same result. In an average of seven experiments, going at a velocity of 28·79 miles per hour, the vehicle was stopped with *skidded* wheels in 190 yards, and at a velocity of 34·4 miles in 241 yards; with the wheels *not skidded*, and going at a velocity of 28·12 miles, the vehicle was pulled up in 127 yards, and at a velocity of 33·75 miles in 179 yards. The adhesion obtained by not skidding the wheels was always greater than that by skidding. The results of these experiments will be clearly seen in the following table :—

| | No of experiments | Velocity in miles per hour | Distance run after application of brake yards. | Adhesion |
|---|---|---|---|---|
| *Lorry.* | | | | |
| Wheels skidded ... | 6 | 26·4 | 87 | $\frac{1}{8 \cdot 6}$ |
| Do. not skidded | 6 | 25·66 | 56 | $\frac{1}{6 \cdot 4}$ |
| *Ghât Brake.* | | | | |
| Wheels skidded ... | 7 | 28·79 | 190 | $\frac{1}{13 \cdot 7}$ |
| Do. not skidded | 4 | 28·12 | 127 | $\frac{1}{10 \cdot 6}$ |
| Wheels skidded ... | 4 | 34·4 | 241 | $\frac{1}{12 \cdot 5}$ |
| Do. not skidded | 4 | 33·7 | 179 | $\frac{1}{10 \cdot 5}$ |

The same experiments were also tried with two vehicles coupled together, one or both being braked, and with the lorry on an *oiled* rail, but not always with the same results.

| | No of Experiments | Velocity in miles per hour | Distance run after application of brake Yards | Adhesion |
|---|---|---|---|---|
| *Ghât and Main line brakes, both vehicles being braked.* | | | | |
| Wheels skidded ... | 3 | 29·7 | 132 | $\frac{1}{9 7}$ |
| Do. not skidded | 3 | 29 7 | 153 | $\frac{1}{11·2}$ |
| *Only Ghât brake on.* | | | | |
| Wheels skidded ... | 5 | 28·48 | 416 | $\frac{1}{14·7}$ |
| Do. not skidded | 6 | 29· | 312 | $\frac{1}{11·5}$ |
| *Lorry on Oiled Rail.* | | | | |
| Wheels skidded ... | 7 | 23·68 | 288 | $\frac{1}{21·4}$ |
| Do. do. ... | 5 | 26· | 344 | $\frac{1}{21·6}$ |
| Do. not skidded | 10 | 24 66 | 372 | $\frac{1}{23}$ |

When both vehicles were braked, they ran *farther* when the wheels were not skidded, which may be accounted for by the difficulty in regulating the brake of the main line vehicle; when only one vehicle, the ghât brake, was braked, by not skidding, they were pulled up *in a shorter distance*; the velocity being nearly the same in all the experiments, the respective distances run by the vehicles after passing the signal, with wheels skidded and with the wheels just allowed to revolve, were 542, 479, 475, 257, 330, and 227, 310, 282, 308, 301, 442 yards; again the lorry was stopped sooner on an oiled rail by skidding.

In addition to these experiments, I tried many others at different times, and came to the conclusion that the point was not of great practical importance. When the rail is greasy and the brake-block is dry there is not much choice in the matter, for the wheel skids at once when the brake is applied; when the rail is dry, the effect of applying the brake firmly is rapid, in either case, in checking the speed. Moreover, it is not always optional whether you shall skid the wheels or not; for, from a constant observation of the action of the brakes in working down the incline, I found it frequently the case, as might, in fact, have been expected, that the front wheel was revolving whilst the rear one was skidded, whilst in a few cases, the wheels could not be got to skid at all; everything depends on the wear of the brake-blocks and the position of the vehicle; and, as the brakes are constantly applied to the vehicles working both up and down the Ghât and round sharp curves, it is difficult to obtain an equal pressure on the two pair of wheels at the same time.

It may be remarked, however, that in certain lines in France, where iron brake-blocks have been substituted for wooden ones, the wheels are allowed to turn slowly in descending the inclines; and it is stated that a "better retardation of the motion of the train is obtained if the blocks are not pressed upon the wheels during the whole time required for the stopping of a train, but are lifted up, and pressed upon again, at very short intervals."

*Brake power on a dry rail.*—I will now refer to the different experiments on brake-power; taking first those on an ordinary dry rail, and secondly those on a damp and oiled rail.

On an ordinary dry rail, the co-efficient of friction varies from $\frac{1}{8}$th to $\frac{1}{15}$th of the weight, and an average of 102 experiments on the descending line makes it to be ·0918, or nearly $\frac{1}{10 \cdot 9}$; this co-efficient, worked out according to the method described above, is rather larger than that obtained by the experiments made on the contrary incline of the catch-siding where it varies from $\frac{1}{11 \cdot 2}$ to $\frac{1}{12 \cdot 4}$. In these latter experiments, the vehicle descended the incline by gravity, and after passing through the points and crossing of the siding, and reaching the point marked A on the section, the brake was applied immediately it began to ascend the contrary incline; and the co-efficient of adhesion is worked out from the

distance run on the ascending line, as in the previous experiments it is from the distance on the descending line.

There is no doubt that a co-efficient of adhesion of $\frac{1}{10{\cdot}9}$ is much lower than what is generally allowed in calculating brake-power. The difference between the results of these experiments and the data given by Mr. Rankine and Mr. Fairbairn would be as follows, in the case of a train running on the level:—

| | | | | | |
|---|---|---|---|---|---|
| Speed in miles ....................................... | 20 | 25 | 30 | 35 | 40 |
| Distance in feet required for stopping train on level, with brakes on all the wheels, according to Mr. Rankine's formula ................. | 96 | 150 | 216 | 291 | 384 |
| Do. do. according Mr. Fairbairn's formula, | 105 | 171 | 242 | 325 | 420 |
| Do. do. according to the Ghât experiments, | 142 | 231 | 327 | 439 | 568 |

For all practical purposes, however, in working the incline, it would be perfectly safe to reckon on a co-efficient of friction of $\frac{1}{15}$ for all trains working over the Ghâts in the day time (from 8 A.M. to 6 P.M.) during all seasons but the monsoon; with this co-efficient, as will be hereafter shown in discussing the experiment on the damp and oiled rail, 35 per cent. of brake-power would keep the train under perfect control on the steepest gradient of the Ghât inclines.

*Experiments with heavy load on dry rail.*—These results are derived from experiments with trains of from 10 to 64 tons weight; as it might have been considered that the experiments were incomplete without testing the efficiency of brake-power on heavy loads at high speed, a train of 200 tons, including the engine, was made up in the following manner: 2 covered cotton wagons and 6 low-sided wagons, each loaded up with fire-bars to 10 tons, and seven 10-ton Ghât brakes, which are open from end to end—weight of load 150 tons, of engine 49 tons; total load, say 200 tons. The train was what may be called a very compact one, and opposed little resistance to the wind; speed was got up at the head of the incline on the 1 in 40 grade.

In the first experiment, after the train had passed over the fog-signals at about 22 miles an hour, the engine and one Ghât brake were braked (30 per cent. brake-power), and after running a short distance, the speed was reduced to 16 or 17 miles an hour; the train kept up this rate steadily all along the incline of 1 in 50, though sand was used to the skidded wheels of the brake, and as I saw there was no prospect of stop-

ping before reaching the 1 in 40 gradient (which had been sanded in case of accident) a second brake was applied (35 per cent. brake-power), and the train was finally pulled up after running a length of 1,540 yards; 30 per cent. brake-power was clearly not sufficient to give a perfect command over the train. In the second experiment, the engine passed the signals at 22½ miles per hour, and 35 per cent. brake-power was then applied, no sand being used; the train was pulled up in 594 yards, not having passed at all on to the 1 in 50 gradient. In the third experiment, the engine passed the signals at 25 miles an hour; 40 per cent. brake-power was put on (engine and three brakes), and the train stopped in 616 yards.

In the fourth experiment, the engine passed the signals at 28⅛ miles per hour; 40 per cent. brake-power, as before, was put on with sand to the leading wheels of the engine, and the train was stopped in 528 yards.

In the fifth experiment, the engine passed the signals at 24·6 miles per hour; with 50 per cent. brake-power (engine and five brakes), and sand to the leading wheels of the engine, the train was pulled up in 379 yards.

And in the sixth and last experiment,* passing over the signals at 28⅛ miles per hour, putting on 50 per cent. brake-power and using sand to leading wheels of engine and three wheels of three brakes, the train stopped in 355 yards.

According to Mr. Fairbairn's formula, in experiments 2 and 3, the train should have stopped in 162 and 178 yards, whereas in practice the distances were 594 and 616 yards; the discrepancy between theory and practice, *on an incline*, is very great in this case.

These experiments show, I think, that the trains are well under command in any *ordinary* condition of the rail with 35 per cent. brake-power, though allowed to attain speeds varying from 22 to 28 miles an hour on nearly the steepest portion of the incline, and confirm the theory laid down above for the necessary amount of brake-power on a dry rail, 2ndly, That most efficient brake-power is afforded by the heavy class of tank engine used on the incline; and 3rdly, That even on a dry rail, sand may sometimes be a valuable adjunct when sand-boxes and sandpipes are in proper working order.

* In these six experiments the engine, pushing behind, was only able in two instances to start the train on the 1 in 40; in the other four cases it was necessary to move down on to the 1 in 50 incline. Steam at 120°.

They also showed me how necessary it was that none but steady reliable men of previous railway experience should ever be appointed to such a responsible post as that of Ghât Guard; for days before, we had been in the habit of experimenting on the 1 in 40 incline at speeds varying from 30 to 42 miles an hour with comparatively light loads, and were almost as much at ease as if we were working on the level; but when a *heavy* train once attains a high speed on a steep gradient, the impetus appears, as it were, irresistible; and then the noise, the grinding action of the brakes, and the rush down the incline, make up altogether a scene, amidst which it is not to be wondered at that a man of fairly good nerve should not always act with that calmness which the position demands of him. In the fourth experiment, two native brakesmen were so impressed with the idea that the train had got out of control, that, contrary to all orders, they rushed to put on their brakes, and were only just stopped in time by Mr. Pinnock, the Locomotive Foreman, who happened to observe them. If this effect be produced when a train is worked during the day time and under the most favorable circumstances, it may well be conceived what steadiness the case demands when a train gets out of control in the dark, when the rails are greasy, and the brake power apparently useless.

*Experiments on damp and oiled rail.*—I will now refer to the experiments that were made in the early morning and on the oiled rail.

The experiments show that the co-efficient of friction on a damp rail ranges from $\frac{1}{14}$ to $\frac{1}{23.8}$, according to the varying condition of the rail, though I have every reason to believe that when the surface of the rail is covered with heavy dew, the co-efficient becomes as low as even $\frac{1}{30}$. It is most unfortunate that I am unable to prove this point from actual practice, for during the whole of the time the experiments were going on there was no instance of a heavy dew; but I think I can show that there is every probability of there being the same variation in adhesion on the damp rail as on the oiled rail, and that if the co-efficient of friction on the latter, from some cause that it is extremely difficult to account for, becomes one morning as low as $\frac{1}{30}$ and $\frac{1}{35}$, there is no reason why the same thing should not occur on the damp or dewy rail, on which the co-efficient is generally as low as on the oiled rail.

In twenty-eight morning experiments, when the rail was not covered with dew, and the surface was only what may be called imperceptibly damp, the co-efficient of friction varied from $\frac{1}{14}$ to $\frac{1}{23{\cdot}8}$, and in fifty-three experiments on the oiled rail from $\frac{1}{12}$ to $\frac{1}{35}$, including the lorry experiments and those on the contrary incline of the catch-siding. The following table shows these results clearly :—

| Rail in early Morning. | | | Oiled Rail. | | | Remarks. |
|---|---|---|---|---|---|---|
| Velocity before application of brake | Distance run after application of brake | Co-efficient of friction | Velocity before application of brake | Distance run after application of brake | Co-efficient of friction | |
| Miles. | Yards. | | Miles. | Yards. | | |
| 25·7 | 396 | $\frac{1}{22{\cdot}9}$ | 30· | 1562 | $\frac{1}{35}$ | All the vehicles were braked. |
| 31·03 | 264 | $\frac{1}{15}$ | 30·4 | 299 | $\frac{1}{17}$ | |
| 33·75 | 443 | $\frac{1}{18{\cdot}7}$ | 32 1 | 1100 | $\frac{1}{30}$ | |
| 34· | 486 | $\frac{1}{20}$ | 32·14 | 385 | $\frac{1}{18}$ | |
| 40·9 | 908 | $\frac{1}{23{\cdot}8}$ | 32·7 | 363 | $\frac{1}{17}$ | |
| 19·15 | More than 1980 | Less than $\frac{1}{16{\cdot}9}$ | 40 9 | 521 | $\frac{1}{17}$ | |
| 23·68 | | „ $\frac{1}{16}$ | 40·9 | 671 | $\frac{1}{19}$ | |
| 27·7 | 1302 | $\frac{1}{20{\cdot}6}$ | 42·8 | 627 | $\frac{1}{17}$ | |
| 29· | 970 | $\frac{1}{18}$ | 22·5 Soaped. | More than 1980 | Less than $\frac{1}{16}$ | 33 per cent. brake-power. |
| 30· | 1069 | $\frac{1}{16{\cdot}5}$ | 25·71 | | „ $\frac{1}{15{\cdot}6}$ | |
| 32·14 | 1146 | $\frac{1}{21{\cdot}7}$ | 33·33 | | „ $\frac{1}{14}$ | |
| 32·14 | 1729 | $\frac{1}{20}$ | 25·71 | 434 | $\frac{1}{14{\cdot}4}$ | 54½ per cent. brake-power. * Run on to sand; in damp rail experiments, rail was not sanded. |
| 32·14 | 2640 | $\frac{1}{20{\cdot}9}$ | 26·47 | 1065 | $\frac{1}{20{\cdot}7}$ | |
| 32·14 | 1650 | $\frac{1}{19{\cdot}6}$ | 29·5 | 560 | $\frac{1}{14\ 4}$ | |
| 26· | 778 | $\frac{1}{19{\cdot}5}$ | 31·* | ... | Less than $\frac{1}{17}$ | |
| 28·125 | 477 | $\frac{1}{17{\cdot}7}$ | | | | |
| 32·14 | 586 | $\frac{1}{16}$ | 32·14 | 586 | $\frac{1}{16}$ | 60 and 65 per cent. brake-power. |
| 33·33 | 940 | $\frac{1}{19}$ | 41·00 | 664 | $\frac{1}{13}$ | |

If, then, the adhesion is proved by a considerable number of experiments to be frequently greater on the oiled than on the damp rail; and experiment also shows that adhesion on the former becomes as low as $\frac{1}{30}$ and $\frac{1}{35}$: is it illogical to suppose that when the damp rail becomes a dewy rail, the co-efficient of friction on it may prove to be nearly as small as on the oiled rail?

I must say that when I first commenced the experiments on the oiled rail, I thought that lubricating the rail freely with castor-oil was a great exaggeration of the effect that would be produced by dew; but with these experiments before me, I am strongly inclined to believe that it is no exaggeration at all.

In support of this I would first briefly notice two experiments that were carried out at the same time on the up and down lines, and the three cases of runaway trains that occurred on the Thull Ghât.

On the morning of the 5th January, the ascending or down line having been oiled, I took the opportunity of testing the running condition of two brakes with which several experiments had been carried out. The two brakes were started together from the head of the incline—the one on the up, the other on the down line; as the joints are slightly against the running on the ascending line, I thought that this might check to a certain extent the velocity of the brake running on that line. The two vehicles, however, with some slight changes of position, passed over the fog-signals at nearly the same moment and at the same velocity, 32·7 miles per hour; the brakes were then immediately applied, and, as of course was anticipated, the vehicle on the dry rail was pulled up first, whilst that on the oiled rail ran 163 yards further.

The experiment was then repeated, and in order to try the extreme case of a vehicle attaining a high speed on what I considered to be as slippery a rail as could occur in practice, I changed the position of the fog-signals, and allowed both vehicles to run freely down the incline of 1 in 40 until they attained a velocity of 41 miles per hour, when both brakes were immediately applied as before, all wheels being skidded. The brake on the oiled rail at once shot ahead of that on the dry rail; but after running about 350 yards, much to our surprise, the brake on the dry rail passed us and was not brought to a stand until it had run for 907 yards, whilst that on the oiled rail stopped in 521 yards.

I will now refer to the three cases of runaway trains on the Thull Ghât, in which I think there is every reason to believe that the engine and brakes were worked with all care, but were nevertheless ineffectual in controlling the speed of the train.

In the case of the 28th October 1868,* the train consisted of—

6 Wagons,
7 Carriages,
1 Main line brake,
4 Ghât brakes,
1 Engine with 6 wheels and bogee;

and the total weight was about 175 tons, of which 100 tons, including the engine, were brake-power. The evidence shows that this train, after running for a quarter of a mile on the 1 in 37, gradually *gained speed* until it had attained a velocity of 30 or 40 miles an hour; that this speed was reduced in passing through No. 4 Tunnel and over the inclines of 1 in 60 and 1 in 73, and that the train finally ran into the catch-siding at from 6 to 10 miles an hour.

Now, if this train gained speed in the 1 in 37, the accelerating force must have been in excess of the retarding force, or the force of gravity must have been greater than the retarding force of the brake-power and the rolling friction. The force of gravity amounted to 60·5 lbs. per ton, and if the rolling friction be put down at $\frac{1}{160}$, or 14 lbs. per ton, a co-efficient of adhesion of $\frac{1}{22}$ would have just kept the train under control, thus—

Three-fifths of weight of train braked, two-fifths rolling free.

Accelerating force .................................. = 60·5 lbs. per ton.

Retarding force = Brake-power + rolling friction $= \frac{3}{5} \cdot \frac{2240}{22} + \frac{2}{5} \cdot 14$ = 66·6 lbs. per ton.

Excess of retarding over accelerating force—5·1 lbs. per ton; but as the train was not retarded, it is clear that the co-efficient of friction must have been much less than $\frac{1}{22}$.

Again, on the 27th December, the mail train consisting of—

10 Carriages,
2 Road vans,
2 Main line brakes,
5 Ghât brakes,
2 large Ghât engines,

* See Appendix Bhore Ghât Commission Report. The cases are taken in the order reported.

got beyond control on the 1 in 37, but was most fortunately pulled up by the sanded rail above the Ehegaum Viaduct, which was then under repair. In this case, the total weight of the train was about 242 tons, 170 tons of which was brake-power, including the engines. With 70 per cent. brake-power this train also gained speed on the same incline. If, therefore, the rolling friction be taken, as before, at $\frac{1}{160}$, the co-efficient of adhesion on that morning must have been less than $\frac{1}{28}$ thus—

Accelerating force of gravity .................... = 60·5 lbs. per ton.

Retarding force of brakes and rolling friction $= \frac{70}{100} \cdot \frac{2240}{28} + \frac{30}{100} \cdot 14$ = 60·2 lbs. per ton.

The Locomotive Superintendent remarks on this accident, that had the timely precaution of sanding the rail been taken, the train would never have exceeded the speed of 10 miles an hour. This may be true, but it is not easy always for men to anticipate what the state of the rails may be, which varies very much on different portions of the incline on the same morning, and the brake-power of the train was, moreover, on that occasion apparently ample. The fact, however, remains good, that according to the evidence, which was very trustworthy, the co-efficient for adhesion on that morning must have been less than $\frac{1}{28}$.

Thirdly, on the 2nd November 1868, a train consisting of—

19 Loaded wagons,
7 Carriages,
3 Incline brakes,
2 Large Ghât engines,

attained an excessive speed between Egutpoora and the Reversing Station, and was only pulled up by running a distance of 300 yards into the catch-siding. Then the total weight of the train with engines was about 282 tons, 70 per cent. of which was brake-power; and if this amount was insufficient to control the speed, the adhesion on the rails in certain portions of the incline must have been, as in the previous case, less than $\frac{1}{28}$. I say on *certain* portions, for the witnesses state that after running about ½ a mile beyond the head of the incline, the speed began to increase until it got up to 20 miles an hour, but that the train *then* maintained the same *uniform* velocity: the adhesion, therefore, on the lower portion

of the incline must have been greater than on the upper, though not sufficient to check the speed of the train.

And, finally, with regard to the fatal Bhore Ghât accident, if a train with 60 per cent. brake-power gains speed on an incline of 1 in 37,—which that train did according to the evidence of the witnesses, though all available brake-power was applied,—it follows that the accelerating force must be in excess of the retarding force. The accelerating force was 60·5 lbs. per ton as before; the retarding force must have been less than this, and the co-efficient of friction therefore less than $\frac{1}{25}$.

In similar runaway cases that occur on the Mauritius incline, Mr. Mosse writes: "In general it is found impossible to check the statements of those working the train, and, assuming them to be true, it would appear that when a train has attained an excessive speed on a slippery rail, all the brake-power which can be applied has but little practical effect."

To all this I know it will be replied, that if the co-efficient of adhesion be so low, how is it that the engines drag their heavy loads up the Ghâts, night and day, with so little difficulty? I can only say that there must be something very different in the adhesion of a skidded wheel going down the incline and the grip of the wheel of the engine going up the incline; that there is a difference is manifest, for on no morning when the adhesion of the brakes was $\frac{1}{20}$ on the descending line could the engine, according to theory, have dragged its load of 200 tons up on the ascending line; whereas it is well known that this duty is accomplished in all weathers, with but very few exceptions, and with no difficulty. I cannot yet see my way to a clear solution of this question.

*Brake-power necessary in working incline.*—It appears, therefore, that, for the safe working of the incline, it is necessary to take into consideration that the co-efficient of friction may often be as low as $\frac{1}{30}$, and that brake-power should be provided to meet this co-efficient in such proportion that the retarding forces of the train shall always be in excess of the accelerating force of gravity, apart from the application of sand. That sand is a most valuable adjunct there can be no doubt, and, with the precautions that are now taken to secure its working efficiently, a train should always be kept under proper control; but times will arise when

sand, sand-boxes, and sand-pipes may not be so well looked after, and it is imperative that the safety of passengers should not be dependent on such liabilities; the safe working of the traffic must also not depend only on trains not being allowed to attain a higher speed than 10 miles an hour, but should, if possible, be ensured, whatever contingency may arise.

In estimating also the brake-power of a train, it is very desirable that the brake-power of the locomotive should be left out of the question; the train should be able to hold itself, and the locomotive too, on every gradient, and in every condition of the rail. Should anything unusual occur, you have then a valuable reserve of power in the locomotive; or should the brake-power of the latter become deranged, there will be sufficient retarding power in the train itself to prevent any acceleration of speed.

*Conclusion.*—Irrespective, then, of the brake-power of the locomotive, if the rolling friction of the carriages is taken at $\frac{1}{160}$ of their weight, every passenger train working on the Ghât should have 77 per cent. of its weight available for brake-power; with a co-efficient of friction of $\frac{1}{30}$, the retarding forces will then always be slightly in excess of the accelerating force; but if a co-efficient of $\frac{1}{35}$ be taken, 93 per cent. would be required, which practically amounts to breaking every carriage in the train.

Let $x =$ required break-power, accelerating force on the 1 in 37 = 60·5 lbs. per ton. Then if rolling friction $= \frac{1}{160}$, or 14 lbs. per ton,

$$\frac{x}{100} \cdot \frac{2240}{30} + \left(\frac{100 - x}{100}\right) 14 = 60 \cdot 5 \quad \therefore x = 77.$$

In the goods trains it would be exceedingly difficult to secure this, and the available brake-power of the locomotive must therefore be relied on to a greater extent. Much, however, may be done to improve the efficiency of the present hand-lever brake, and the blocks should be made to act on both pairs of wheels.

*Rolling friction.*—The rolling friction, which includes the friction of the axle, of the wheel against the rail, and the resistance of the air, varies considerably in all the experiments. Neglecting experiments in which the velocity was calculated over too great a length between the fog-signals, the co-efficient of friction ranges between $\frac{1}{90}$ and $\frac{1}{274}$: this is no doubt a very

considerable range; but it must be recollected—1st, That the deductions are made from a vehicle allowed to fall absolutely from a state of rest, and that if the wheels and axle-boxes are not in good order, a considerable amount of velocity is lost in the slowness of the starting; 2ndly, That allowance must be made for errors occurring from time to time in registering the velocity with the chronographs. I had, unfortunately, no instruments capable of doing this with *perfect* accuracy; 3rdly, The velocity shown in all cases is slightly below the real final velocity, which would make the co-efficient of friction and adhesion slightly less than they have been worked out.

The average of the experiments on the descending line shows the average co-efficient throughout the whole length the vehicle ran to be $\frac{1}{125}$, or from 17 to 18 lbs. per ton, at velocities varying from 18 to 42 miles an hour; and the average of 18 experiments made in the catch-siding gives a co-efficient of $\frac{1}{145}$, or 15 lbs. per ton for velocities up to 47 miles an hour. The latter result I believe to be the more correct, as less element of error enters into the calculations. I endeavoured to find out the resistance due to passing through the points and crossings, but the instruments would not register this with sufficient accuracy. If, however, friction of 1 lb. per ton were allowed for this increased resistance, the co-efficient would then be $\frac{1}{160}$ of the weight, or 14 lbs. per ton, for vehicles working on the Ghât incline.

If these results be compared with Mr. Daniel Clark's formula $8 + \frac{v^2}{171}$, it will be found that in a considerable number of the experiments at the higher velocities of 30 to 40 miles an hour, there is not much difference in the results. It is in the lower velocities that difference occurs, the experiments giving a larger amount of friction than is generally allowed for. In fact, in comparing the different experiments, I find it quite impossible to work out the rolling friction according to the varying velocity, for the experiments at the lower speeds often give a larger amount of friction than those at the higher (up to 47 miles an hour). It is only when the vehicle is allowed to run a considerable distance, and to get up a very high velocity, that the great increase of friction with the velocity becomes quite apparent. At a velocity of 58·6 miles per hour, the resistances according to Mr. Clark's formula would be $8 + \frac{58{\cdot}6^2}{171} = 28$ lbs.;

experiment 208 at this velocity shows that the *average* resistance throughout the whole run is 22 lbs. per ton. Again, in experiments 212, 213, 214, the formula would give a final resistance of 30, 30, and 28 lbs. but the experiments show that there is an *average* resistance throughout the whole run of 27, 29, and 30 lbs. per ton. This is a very considerable discrepancy, and can only be accounted for by the resistance increasing in a much greater ratio to the velocity than is given in the formula. To lay down a law for this would have required a very much larger number of experiments than have yet been carried out; but I think this much is probably true, that the resistances of trains at high velocities are considerably in excess of the amount that is usually estimated, which is derived too, in most cases, from Mr. D. Clark's formula.

*Experiments in Catch-siding.*—I think this will appear more clear if experiment 215 be examined. I will first state briefly how this was carried out.

Six low-sided wagons coupled together, each laden with earth up to 10 tons, were let loose from the head of the incline below the reversing station and allowed to descend by gravity; the rails of the catch-siding, being old and rough, were oiled throughout the whole length of the siding, in order to represent a slippery condition of the rail; of course, it was impracticable to do this on the main line—the points of the siding were spiked down, and the fog-signals placed at the foot of the descending gradient at an interval of 88 yards.

The distance of the head of the incline from the catch-siding is exactly 5 miles; the height fallen through is 621 feet; length of the catch-siding 1,276 yards, and height 159·6 feet.

The wagons were let loose at 7-50 (in the morning) and reached the points of the catch-siding at 7-55 exactly, having done the distance in 5 minutes, at an average velocity of 60 miles an hour; they passed the points of the siding at the rate of 75 miles an hour, going over the 88 yards between the signals in 2·4 seconds. Looking down on the wagons from a knoll above the entrance to the siding, they *appeared* to pass with ease through the points and the crossing, and I expected that, as in the previous experiments, there was no increase of velocity, they would run only some few feet higher than in the previous experiments, and would then return down the incline of the siding. The end of the catch-siding was not visible from where we stood, but the rise of a cloud of

dust soon told us that some accident had happened at the end of the siding. Mr. Pinnock, the locomotive foreman, who was stationed a few yards beyond where the wagons had generally run, informed me that they passed him with considerable speed, which they must have, for they struck the dead end of the siding with such force that the leading wagon was found a perfect wreck with its framework upside down in No. 2 wagon. No. 2 wagon was also nearly destroyed, and the others more or less damaged. It will be noticed from the section of the siding that all this occurred on the gradient of 1 in 3; the only way of accounting for the vehicles running so much higher than in the previous experiments, when the *velocities are considered*, is, that they steadied each other in passing through the points and crossing, and the resistance of the air must have been less per vehicle.

Now, if the velocity attained in the experiment be examined, it will be found that there was an average friction throughout the whole run of 37 lbs. per ton; the formula would give a final resistance of 41 lbs.

$$W\left(h - \frac{v^2}{2g}\right) = l f M$$

$$\therefore M f = \frac{\left(621 - \frac{110^2}{64 \cdot 3}\right) W}{26400}$$

$$= \frac{1}{60} W$$

or 37 lbs. per ton.

What then, it is required to ascertain is the ratio between the total resistances and the velocity; experiments 205 to 215 will not determine this clearly, but if the velocity of a vehicle were taken at certain intervals of, say, $\frac{1}{4}$ of a mile, in the descent of the incline, it would then readily be seen when the maximum speed was attained and the force of gravity was counteracted by the resistances. I need hardly say that there would be considerable risk in taking these observations in the vehicle itself, and to have ascertained it in any other way required a larger number of instruments than were at my disposal. In the last experiment I did endeavour to ascertain the velocity midway, but the person who had charge of the chronograph, being flurried by the sudden rush of the vehicles past him, failed to take an accurate observation.

Regarding the catch-siding itself, it should be remarked, that in all the

experiments that were made the points were carefully spiked down; the vehicle entered the points without much oscillation, but always swayed *very badly* at the crossing. If a runaway train were to enter the siding at any speed with the brakes well on, as they would be, the elasticity of the springs would to a certain extent be diminished, and the vehicles would not take the crossing so easily. Moreover, if the points were not firmly held, the engine running at speed might, by a blow on the switch-rail, spring the points so as to throw the following vehicle off the line. I do not say that the entrance to the siding is unsafe, but these points have to be considered. I am not aware that anything can be done to remedy the crossing, but the very best description of facing point should be adopted for all catch-sidings on the incline. I believe there have been improvements lately in facing points on English railways which would obviate the danger I allude to.

I saw no necessity for testing the height of the catch-siding with a runaway train; if vehicles running freely at 60 miles an hour only attained to a height of 59 feet out of the total height of 159 feet of the siding, no train running away with its brakes on would reach anywhere near the end. Even when the catch-siding was oiled, it will be observed from experiments 223 to 230, that after the vehicle, going at a velocity of 32 miles an hour, was braked on the contrary incline, it only ran 343 yards (out of total length of 1,276 yards), and attained a height of only 4·3 feet.

*Working incline with fixed amount of brake-power to passenger carriages.*—As it appeared to me of some interest to ascertain what should be the fixed amount of brake-power in working down the Ghâts on an ordinary dry rail, supposing that self-acting brakes were used, and that the engine running free should drag the train down at the rate of 10 to 12 miles an hour, a light train was made up of 6 vehicles, 3 Ghâts brakes, and the engine, weighing altogether 112 tons 18 cwt.

In the first experiment, 18 per cent. of the train was braked (the wheels of 4 wagons being spragged); the engine having put on steam on the 1 in 40, the train moved on at a low speed, and steam was then shut off; the train did not stop, but kept up the same steady rate.

An additional wagon was then braked in four wheels (giving 24 per cent. brake-power), and the train started as before; after running a short distance it was brought to a stand; 21 per cent. brake-power was then

tried, but this also proved too much, and the train was again stopped.

I concluded, therefore, to try the amount of fixed brake-power in the first experiment, viz. 18 per cent. Having started the train and shut off steam, we proceeded at a steady rate of 10 to 12 miles an hour, but on reaching the 40-chain curve on the 1 in 50 incline, the speed became too low; steam was then put on for a few seconds, again shut off, and the train, going at a steady rate of 10 to 12 miles an hour, finally pulled up on the 1 in 330 at Khandalla Station without applying any additional brake-power.

It is interesting to remark here, that practice corresponds with the results derived from experiment on a perfectly dry rail; for the train to maintain a uniform speed on an incline of 1 in 40, the accelerating forces must be slighty in excess of the retarding forces. They were so in the present instance, and reasoning from this fact, the co-efficient of friction works out between $\frac{1}{9}$ and $\frac{1}{10}$.

*Working train with fixed brake-power over oiled rail.*—On the 18th January I tried the same experiment on an *oiled rail*, the train being made up as follows:—

1 Engine.
3 Ghât brakes.
4 Low-sided wagons. ............................................ } Empty.
2 Cotton wagons (with Mr. Bell's self-acting brake attached.) }

Weight of engine 49 tons, of train 64 tons; total 113 tons.

In order to be certain as to the state of the rail I made two experiments, which showed the co-efficient of friction to be $\frac{1}{30}$ and $\frac{1}{35}$; the rail was therefore the most slippery that I had yet experienced. This being the case, and to guard against all chance of accident, all the vehicles of the train were braked (the wheels of the four low-sided wagons being spragged), and the engine allowed to run free (as a carriage) on to the oil; but when steam was shut off, the train pulled up almost immediately, a certain portion of it not having worked on to the oiled rail.

The Ghât brakes were then taken off, and the train again started with about 30 per cent. brake-power, the engine running freely in front. A speed of 10 to 12 miles an hour was then kept up to the end of the incline of 1 in 40 and on to the 1 in 50; but after running some length on this

gradient, as this speed began to increase, another brake was applied (38 per cent.), which brought down the speed too low, and was therefore again taken off. We, therefore, worked the train with the former, 30 per cent., brake-power, which maintained it at a nearly uniform speed, until we were pulled up by running on to the sanded rail.

It would appear from this experiment that with *great* care the incline may be worked with safety under very trying circumstances, but that it is of the utmost importance that the slightest increase of speed should be at once checked; for this purpose there must be available brake-power, and it is this which strikes me as the weak point in the present working of the Ghât, that there is no brake-power to spare. As the carriages do not sustain themselves, all the work is thrown on the incline brakes; if these and the engine prove insufficient there is only the rear main line brake (which is not ordinarily used) and the use of sand to fall back upon; when every vehicle of the train is braked, and the arrangements for sanding are in good working order, all is done that can be done; and if the train runs away under these circumstances (supposing that there is no carelessness) the conclusion is, as remarked by Mr. Mosse, regarding the Mauritius incline, that the gradient is too steep. On the Indian inclines, however, we have not yet reached this point, for the available brake-power is not more than 60 to 70 per cent., and much can yet be done to secure greater safety.

I may mention, that after the train had been worked down over the oiled rail, as it was necessary to return to Lanowlee without delay, we tested the power of the engine in working it back over the same incline. Though the engine was working at first on a sanded rail, the wheels had been so thoroughly oiled, she experienced great difficulty in starting: once started, however, she was able, with 120 lbs. pressure of steam, to push the load up at the rate of 2 miles an hour, at which rate the train was worked for some 5 or 600 yards on the 1 in 40, when, to relieve the engine, the sand was brought into use; this acted like magic, and after a few revolutions the engine pushed the train at the rate of 20 miles an hour up to the end of the oiled rail with perfect ease. When the rail is damp or oiled, the sand, of course, adheres to the rail more readily, and its efficiency is much increased.

*Sand.*—On the damp* rail the action of sand is very variable. I will

* Experiments were made in the early morning at 6 and 6-30 A.M., so that the rail was not actually dry.

now refer to the different experiments that were made upon the use of sand; but it should be remarked, that it was difficult to obtain a *large* number of experiments, as, when the oiled rail was once sanded, the line was spoilt for further experiments that morning. In the following table the results are tabulated:—

| No of Experiment. | Description of Vehicle or Vehicles. | Brake-power per cent. | Before applying brake, miles per hour. | Distance run after applying brake, yards. | Co-efficient of adhesion. |
|---|---|---|---|---|---|
| 195 | Train of 200 tons, including engine. | 30 & 35 | 22 5 | 1,540 | Less than, .. .. $\frac{1}{14}$ |
| 198 | | 40 | 28·125 | 528 | Comparatively dry rail, .. .. $\frac{1}{10·5}$ |
| 199 | | 50 | 24·6 | 380 | $\frac{1}{12·7}$ |
| 200 | | 50 | 28·125 | 352 | $\frac{1}{10·7}$ |
| 105 | 3 Incline brakes. | 35 | 31·03 | 1,370 | Sand on soaped rail, $\frac{1}{12}$ |
| 125 | | 33 | 32·14 | 710 | Sand on oil,.. .. $\frac{1}{9}$ |
| 100 | | 35 | 33·33 | 692 | Sand on dry rail, $\frac{1}{8·9}$ |
| 101 | | 34 | 30· | 718 | Do. do., $\frac{1}{10·4}$ |
| 102 | | 34 | 36· | 800 | Do. do., $\frac{1}{9·1}$ |
| 103 | | 34 | 36· | 960 | Do. do., $\frac{1}{10·1}$ |
| 104 | | 34 | 36· | 2,794 | Do. do., $\frac{1}{15}$ |
| 157 | 2 brakes. | 50 | 36·7 | 387 | Do. do., $\frac{1}{9}$ |
| 226 to 229 | 3 brakes. | 66 | 29 to 31 | 252 | Sand on steel rail, $\frac{1}{10·7}$ |

It will thus be seen that there is not any advantage in some instances in using sand on the damp rail, and that in experiment 104 it was apparently of no use at all.

Experiments 101, 102, 103, 104, were carried out consecutively on the same morning; the fog-signals were placed at the same point in each experiment; and as the vehicles, therefore, ran braked over the same section of the line in each instance, it was to have been expected that—the rail being roughened by the sand used—the vehicles would have been pulled up in the shorter length each time and that the co-efficient of adhesion would have been larger. It was not so, however; the co-efficient was

greatest in the second experiment; in the third experiment, the co-efficient was less than in the second, and vehicles ran 160 yards further; and in the fourth, the co-efficient was as low as $\frac{1}{15}$, and the brakes were not pulled up until they had run 2,794 yards. There was no doubt about the sand-boxes and pipes being in good order; for I stood on the foot-board of the brake, and watched the sand being steadily delivered on to the rail, close to the wheel: it seemed, however, to produce no effect. In the experiments also that were made with the heavy train, the adhesion was not always increased by sand; experiments 196 and 197, where no sand was used, giving better results than some of the other experiments. On the oiled rail, its effects are very apparent, for the co-efficient of adhesion was thereby at once reduced from $\frac{1}{18}$ to $\frac{1}{9}$; though it may be noted that, on the same morning on which this experiment was tried,—the oiled rail having been freely sanded from the two sand-boxes of the leading brake,—when the engine of the mail train (ascending incline) arrived at this part of the line, it was quite unable to move its load, and it was found necessary to re-sand the rails from a sand-lorry, and send a second engine down from Lanowlee to assist. If, on this latter occasion, the use of sand on oil had developed an adhesion of $\frac{1}{9}$, the engine would have been able to move the train, for the resistances amounted to 11,750 lbs., and one-ninth the weight of the engine to 12,444 lbs. (*see* above as to tractive power); but it is evident that for the ascending train the co-efficient was less than this,

| | | lbs. |
|---|---|---|
| Resistance of gravity, | $\frac{160 \cdot 2240}{40}$ = | 8,960 |
| Resistance of load 110 × 14, | = | 1,540 |
| Do. engine 50 × 25, | = | 1,250 |
| | Total resistance, .. | 11,750 |

There can, I think, be no doubt as to the advantage to be derived from the use of sand on a damp rail: experience has demonstrated this all over the world: but it is of great importance that the sand-pipes should work as closely to the rail as possible, as in running round curves, owing to the swaying motion of the vehicle, the sand is often thrown clear of the rail, or very little is deposited. The sand-pipes used on the Ghât brakes

undoubtedly deliver well on to the rail, but not having a flexible end they are apt to be twisted by any imperfection in the permanent-way, and then, of course, become perfectly useless.

*Steel Rails.*—As the co-efficient of adhesion is generally considered to be less on the steel rail, I carried out experiments 231 to 240; from these it will be seen that the co-efficient varied from $\frac{1}{12 \cdot 7}$ to $\frac{1}{17}$, which is a decidedly smaller co-efficient than on the ordinary rail. When sand was used, the co-efficient varied from $\frac{1}{9}$ to $\frac{1}{12}$, the average being $\frac{1}{10 \cdot 7}$. The subject, however, is not of much importance, for whatever brake-power be eventually provided to meet an extremely slippery condition of the ordinary rail, will be sufficient to allow for the slight loss of adhesion that there is on the steel rail.

*Rolling friction of engine.*—Regarding the rolling friction of the engine, the experiments, 241 to 264, show that this is greater than what is generally estimated. In twenty-four experiments the friction varies from $\frac{1}{101 \cdot 8}$ to $\frac{1}{70}$ of the weight; twenty-one of these results are derived from experiments made on the descending line, the engine being allowed to run as a carriage; and the remaining three from experiments in the catch-siding. The former give an average resistance of 28·6 ℔s. per ton, the latter of 23 ℔s.: everything, of course, depends on the description of the engine, and its condition. The engines experimented on were the 8-wheel coupled Tank engines used on the Bhore Ghât—diameter of wheels 48″, of cylinder 18″, length of stroke 24″. As the friction appeared rather large, I endeavoured to test it approximately by the load of Ghât engines that a Ghât engine would draw on the level. The pressure of steam was 120 lbs. and the weight of the engine 49 tons; its traction power would, therefore, be $\frac{18^2 \times 120 \times 24}{84} = 19{,}440$ lbs.

then, load an engine will drag $= \frac{\text{Traction power}}{\text{Resistance in lbs. per ton.}} -$ its own weight.

$$\text{or Resistance} = \frac{\text{Traction power}}{\text{Load} + \text{weight of engine.}}$$

It was found that the engine could drag 14 Ghât engines, weighing altogether 560 tons, at the rate of ½ to ¾ of a mile an hour. I have no

doubt the engine would have done more, but the strain on it was so great, from trying the experiments both on a dry, and on an oiled, rail, that it was not considered advisable to continue the experiment. Allowing, however, that the load was 600 tons, the resistance of the engines dragged was $\frac{19440}{600 + 49,}$ or about 30 lbs. per ton, and the adhesion $\frac{1}{5 \cdot 4}$. The oiling the rail made no difference, except that more time was taken to move the load; the wheels slipped, and burnt up the oil; the engine then moved forward slightly, stopped again, and so on until the distance was accomplished.

In reversing the engine and applying the brake, the friction obtained from an average of eleven experiments was $\frac{1}{10 \cdot 9}$, or ·0914 of the weight, and the three experiments made on the catch-siding show a co-efficient of $\frac{1}{11 \cdot 5}$; it will be seen that there is very little difference in the result of the experiments on the brakes and on the engine. In both instances, the experiments on the contrary incline of the catch-siding show a less adhesion than those carried out on the descending line; and the bad effect of skidding the wheels is also very apparent.

Beyond these points, I do not consider that I am called to go into the further question of the proper system of working the Ghâts. Whatever system of brake-power be adopted, it is essential, as laid down by Mr. Hawkshaw regarding brake-power in general, that it shall be equally under the command of the engine-driver and guard; both should, if possible, have an independent command of the power by which a train may be stopped. If the suggestions made in Mr. Berkley's report of using Clark's new continuous brake be carried out, and prove successful, the whole difficulty is met; but if they are not successful, it is very probable that, by increasing the number of compound Ghât brake carriages, and attaching a self-acting brake to all but first class carriages, safety in the future working of the Ghât may always be relied on.

J. H. W.

*February*, 1870.

# No. CCLXXX.

## BOMBAY RECLAMATION WORKS.

By James B. Chalmers, Esq., C.E.

The amount of capital sunk by a public Company in engineering operations, and the mode in which it has been utilized, are always subjects of interest to the Engineer.

The author will, therefore, preface his account of some of the works of the late Elphinstone Land and Press Company, Bombay, with some general information regarding them.

This Company was formed eleven years ago for two objects:—

1st, The reclamation of land from the foreshore of the busiest portion of the harbour of Bombay opposite and close to the native town; and 2nd, For pressing cotton.

The terms upon which the Company obtained the concession of this foreshore, were principally:—That the Company reclaim a quantity of land for Government, sufficient to form a harbour terminus for the Great Indian Peninsula Railway, powers being given them to levy, from the first, tonnage, harbour and some minor dues.

The capital with which they started was one hundred and eight lakhs of rupees.

Their object as a pressing Company was soon lost sight of, and up to the year 1865, their attention was almost wholly occupied in redeeming their concession, by reclaiming the principal part of the land due to Government thereon, and in levying dues on the old quays.

From this time, they began in earnest to form land for themselves, and their original capital having been severely taxed, they formed a second capital equal to the first.

Their property, as they reclaimed it, absorbing the existing quays, their position on the foreshore required them to provide new harbour accommodation for the merchandize of Bombay.

But this object was with them quite subsidiary to the formation of land, which they appear to have anticipated would be rapidly seized upon by a pent-up sea-port population; and indeed, on no other supposition, can it be conceived how the capital was so in-commensurate with the project, how its ultimate cost does not appear at any time to have been approximately calculated, and how, in its design as a harbour, no attempt was made, till too late in the history of the enterprise, to improve on the old quay walls.

The methods employed for loading and unloading goods in that most magnificent harbour were then, and are now, of the most primitive and antique type, such as, prior to 1805, gave to the river Thames so bad a notoriety; native lighters being the medium of transferring cargo from ships to the shore.

The Elphinstone Land Company's plans merely contemplated the continuance of this system; increasing, but in no way improving, the existing accommodation, and their first recognition of their position as harbour proprietors, was in 1865, when their estate, as previously outlined, was divided into land estate and dock estate. The credit of this is due to Mr. Fleming, late of Bombay.

They thus recognised themselves as also a Dock Company, but so little did this influence them, that after ten years monopoly of the finest part of the foreshore of the harbour of Bombay, and the absorption, by their works, of two successive capitals, there has not been substituted much more of quay walling than that which their reclamation absorbed.

This comparison of quantity would not be fair criticism, if the new walls were, in any way, improvements on those which they superseded. But the new walling is, like the old walling, fitted only for the reception of coasting steamers and native craft: European vessels still anchoring in the stream. There is no machinery with which to lift heavy merchandise, with the exception of a pair of shears, previously, the author believes, in use on the old quays.

As a Land Company, they have been successful in reclaiming 185 acres of land at a cost of 175 lakhs of rupees, from which there has been derived a nearly stationary dividend of about 4 lakhs net from revenue sources, while their profit from sales of property is merely a nominal sum of Rs. 1,203.

Having thus formed a large extent of land, and reimbursed to the public of Bombay their ancient quay walls, the future policy of the Directors of the Company was to have called into existence a third capital of 100 lakhs, with which to complete the Dock Estate, with accommodation for large vessels, the Directors correctly stating that no material increase of dividend could be expected until this was done. It was intended that this third capital should have been formed from proceeds from sales of the newly formed land.

It does not require to be demonstrated in the year 1870, that land adjacent to docks depends for its exceptional value on the existence of the docks, while the value of docks depends on other conditions than on abundance of adjacent land, so that the proposition of the Directors to sell this land before the docks were made, was a proposition to sell the property of the shareholders on the eve of its becoming valuable.

The idea which they ought to have kept more prominently before their minds than any other idea, was that the Dock Estate property developed would alone make the land estate valuable, and would, without fail, have furnished funds with which to form a highly valuable land estate.

The problem which they had to solve was the following :—

Given, the concession of foreshore for a land and dock estate. Given, a capital sufficient only to create one of these estates. Required, which estate should have the precedence in construction.

The consequent problem for the Engineer was, how to construct the dock estate simultaneously with, or antecedently to, the land estate. It is no part of the author's intention to solve this engineering problem, although he fails to perceive any other than ordinary difficulties therein.

That they either failed to perceive the importance of the precedence of the Dock Estate in time of construction, or that their engineers failed to show how that could be advantageously done, is matter of Bombay history; but before they spent two capitals in forming land alone, while their deep water dock was still unformed, the mine of wealth which lay therein unworked, and around which port industries must soon have crowded, it

would have been well had they made sure they were acting wisely, by having obtained beforehand a careful analysis of the history and conditions of dock enterprise, before they launched into the formation of barren land; by having ordered to be prepared, beforehand, drawings of the whole of their works, careful estimates of their cost, and a clear description of the most economical way of carrying them out, such as in England must be done, and often in the face of a keen sighted parliamentry opposition.

The land formed by the Company has now been sold to Government for Indian 4 per cent. paper, a most inadequate return for the money, the patience, and the reasonable expectations of the shareholders.

The land was formed in three different ways :—

I. Earth brought by railway trains under contractors.

II. Earth brought by barges belonging to the company under the superintendence of their Engineering Staff.

III. Earth brought by native prows under contractors.

The earth brought by railway train along the G .I. P. Railway from Coorla hill, a distance of 8 miles, at the busiest times was about 12 trains daily, or one hourly, of 30 ballast wagons, each wagon carrying from 5 to 7 cubic yards of earth, or about 2,000 cubic yards daily.

This hill was composed greatly of clay and rotten rock, and was brought down in vast quantities by means of mines.

The author is unable to furnish any information from his own personal knowledge of the detail of the operations in bringing earth in for reclamation; but Mr. W. H. Scott, now Local Fund Engineer, at Dharwar, could furnish an interesting paper on the various methods adopted in reclaiming the foreshore.

The Engineer had three things to do, and writing them in the order in which they have been, or were proposed to be done, they are—

I. Reclaiming land.

II. Forming deep water docks.

III. Dredging a channel.

The land is now formed, the docks are still to build, and the channel to cut.

It appears to the author that the order of these three operations might with great propriety and much economy have been reversed.

I. The material to be dredged is a stiff yellow clay intermixed with hard moorum, admirably adapted for reclamation, and when dredged, must be deposited to spoil somewhere in the harbour.

Had this channel been taken in hand first before the reclamation was advanced, instead of being postponed to the last, the author can see no reason why it should not have been used for reclamation, at a cost little, if any, over what it must eventually have cost for dredging and depositing.

It has formed no part of the author's purpose to show how this could have been done, but it is a very simple problem indeed, and by no means new one.

Dredging and depositing on the river Clyde with a long water carriage averaging not less than 15 miles, costs only 6*d.*, or 4 annas per cubic yard, which cost suppose doubled for Bombay, and allow handsomely for the spreading and levelling above high-water-mark, then as reclamation alone has cost 97 lakhs there is a saving of 70 lakhs.

With a channel dredged and the construction of a dock for vessels following close upon its heels, the revenue would have amounted, not steadily, but with a bound, and whatever land was then formed would at once have been of exceptional value.

The second problem presented to the Engineer was to construct his dock for large vessels, maintaining intact in the meantime, the existing amount of accommodation for small craft, and means of communication between his large dock, and the old land with its ware-houses, &c.; this was by no means a problem of difficulty, and it is to be regretted exceedingly, both in the interests of the port of Bombay and of the shareholders, that its solution was not arrived at.

In thus indicating the order which, in these three operations, might and ought to have been observed, and the engineering problems connected with them that, had they been solved, would have led to the saving of the shareholders' capital, and the immense improvement of their revenue; the author considers only the recently present state of the importance of the harbour of Bombay, but there are not sufficient data for calculating the importance of the immediate future, now that the railway to Calcutta and the Suez canal are opened.

Having thus given a general sketch of what has been done, what has been left undone, and what ought to have been done, the author will now proceed to the more immediate purpose of this paper, by giving a

description af some works connected with this Company, in which he was specially concerned.

Up to December 1865, the work of building seawall had been carried on departmentally.

At this and a subsequent time the author contracted to build from the points A, B and C.

From the points A and B, the Engineers had made preparations in the way of coffer-dams, engines, stone from Mowroree Hill, &c., and the contract for these two portions was for labor only.

From the point C, the author supplied his own plant and made his own arrangements.

I. WALLING AT A.—From whatever cause, the arrangements at A were neither so complete nor so well considered as at B.

North of the point A, the foundation had been laid on a reef bare at low water of spring tides, the material being brought alongside in three barges, one roomy barge holding rubble, one flat bottomed barge (such as shown in *Plate* XXII.) holding the ashlar facing stones, and mounted with a wooden crane employed in the setting of them, and one flat punt holding mortar.

South of the point A, three, four or five feet of sandy mud overlay the foundation, and the arrangements made for removing this consisted in two coffer-dams each about 80 feet long, the first of wood, the second of iron.

The wooden coffer-dam was of single piling, 8 inches thick, of Kaura pine, admirably suited in strength and straightness of grain for the purpose, driven into 4 feet of sandy mud.

The effective height was less than half tide, but its real height was very irregular, a large proportion of the piles being 24 feet long or of a height more than sufficient for a full tide dam.

With this great height and so little hold in the foundation, means had to be taken to prevent its falling in pieces. The means used consisted in weaving several hundred lineal feet of heavy chain from side to side of the dam, gathering it into several groups and twisting them up into "Spanish Windlasses." This, like all make shifts, was imperfect, and the seams could not be kept tight although caulked.

*Pumping arrangements.*—A Gwynne's centrifugal pump of 9 inches dia-

meter in discharge, driven by a portable engine of about 6 horse-power, placed upon the end of the finished wall, raised the water from 14 to 18 feet over the piling.

This engine was found too small to work so large a pump so high, four or five of the piles were cut down, and the pump lowered about 5 feet. A small stream of water was then obtained; but owing to a great leakage through the finished wall, the power was quite inadequate to the duty.

Another single cylinder portable engine (8 H. P., Allen's patent) was substituted, but unfortunately a large portion of the cylinder was occupied by a patent steam expanding apparatus, so that although an easy foundation, the men engaged in digging worked constantly in 2 or 3 feet of water. The men did little work so situated, and the expense of digging foundations was still further enhanced by the great height of the piles, as ladders had to be placed in the dam upon which men sat, and the wet sandy mud was taken over the piles hand over hand. The author, by crowding men into this dam, succeeded in founding it, although at a great expense.

The second or iron dam, was a double dam composed of a double row of main piles formed from contractor's rails pointed, between the grooves of which ⅜-inch iron boiler plates were supposed to be slipped and driven through the sandy mud by a heavy hammer. After a few plates had been driven, this method was abandoned as too troublesome; so the greater part of it was built by placing the iron plates against, instead of into, the grooves and retaining them in their places by a confused mass of chain. The space between the double wall of rails and plates was meant to be filled by the excavated sandy mud, as the digging progressed, but the plates were dislodged by every swell of the sea.

The dam (*See Plate* XXII.) is shown as it would have been, had it been constructed as intended, as nothing but a photograph could have done justice to the great tangle dmass of chain, and the irregular appearance of the iron plates.

It was found impossible to lower the water in this dam, and the author attemped to take out the excavation without pumping, but failed to make it as clean as desired. He was for this reason obliged to abandon his attempt to build the wall at A, until the Engineers had matured their arrangements.

The means ultimately adopted consisted of wooden caissons floated to the site, arranged around the part to be founded, loaded with iron rails, filled with mud, brought from Clerk Basin by one of the company's barges, with a 14 H. P. Clayton Engine to work the pump. The work, now easy, was handed over to a native contractor, previously a mistree in the company's service, and having thus some experience of tide work. To get rid, it is presumed, of the unfortunate iron dam, the contractor was allowed to put in concrete for a foundation into it, in the exact state in which the author had left it.

The damming by caissons was still carried on departmentally.

WALLING AT B.—The arrangements for this work are shown on *Plate* XXII.

The depth of excavation was about 9 feet, through a firm clay.

*Coffer-Dams.*—The piling was driven in the way usual in small works, but it may not be out of place to describe it. The method employed is shown in *Plate* XXIV.

Every 10 feet on either side, a main pile was driven from a flat punt mounting a fixed piling engine; one or two of these piles was all that could be driven in a tide. The flat was stranded in its place, as the water receded when a pile was driven; sometimes another pile was driven when the flat was floating. If it could be sufficiently steadied for the first few blows, the pile engine was lashed to the pile so as to steady the flat and make the blow true.

Several main piles having been driven, walings were then bolted on each inner side forming a skeleton dam. Moveable cross pieces were then laid upon these walings, and these recrossed by other pieces to serve as rails. Upon these were placed ordinary hand piling engines, and the sheeting filled in.

The pile engines were pulled along upon the rail pieces by means of block and tackle fixed to one of the more distant main piles, assisted by pinch bars. The joints were then caulked.

*Pumping.*—The power for pumping was ample, consisting of a Clayton and Shuttleworth's 14 H. P. portable engine, double cylindered, working a 9-inch discharge Gwynne's centrifugal pump.

Single cylinder engines are not well adapted for these works; when the water has been pumped out, intermittent pumping has to be carried on to keep down leakage, and a single cylinder engine is sure to stop over the

dead points of the crank, and requires the attendance of several men at the fly wheel to start it.

The author experienced the miseries attendant on working with a centrifugal pump in a muddy harbour, especially in the night tides with the uncertain light of tarred ropes or naphtha lamps. If a chip of wood, a bit of oakum, a pebble no larger than a pea had got about the foot valves at the last time of stopping work, the pump had to be lifted bodily up out of the water, put in again, adjusted to the engine belt, and fanged, by which time a tide had been lost; a grating over the foot valves was found to make matters worse. This was a matter of great moment, as owing to the great diurnal inequality of the tides at Bombay, the average number of spring tides suitable for putting in a foundation, was about eight each spring.

The working hours in these foundations were further seriously encroached upon in this way. The reclamation had been pushed up close behind the coffer-damming, and the tidal water had a very confined outlet, so that a large quantity of back water finding its way through the porous reclamation, composed mostly of a rotten rock, entered the dam below the line of caulking, and had to be pumped daily. This might have been partially stopped by throwing the clay from the dam over that side, but the staging was on the other side, and the expense would have been balanced. Latterly, some barge loads of clayey earth were thrown on that side with good effect.

*Staging and Excavating.*—In front of the piling on the harbour side, was a staging extending above high water, on which two Taylor's travelling steam cranes moved. It was with these the pumps were lifted and replaced. They were also used in the excavation. To each crane was attached two iron buckets into which the clay was thrown as dug, and these buckets were drawn up alternately and tipped over the staging into the basin.

*Building.*—The material for building was brought in barges as at A which lay outside of the staging, and of each other in the order shown in *Plate* XXII. The rubble barge lay outermost, and the rubble and mortar were taken over the staging and into the dam hand over hand.

At one place where a number of piles half-tide high happened to be grouped together, the author laid a gangway with advantage under the arches of the staging.

The ashlar barge lay next the staging. The stones were lifted from

the hold by the wooden crane in the ashlar barge, and laid along the edge. From thence they were hooked by the steam crane, lifted over the staging and lowered into their place on the wall.

Having finished a length of 50 or 60 feet, the pumping engine and pump were shifted forward to the end of the dam, in which there was building, this end having been kept clear for the purpose, and cut off by pieces of wood.

FAILURE OF 300 LINEAL FEET OF WALLING..—The author, before proceeding to describe the building of the wall from C, will refer to the instructive failure of the wall from C to D, *Plate* XXI., built departmentally.

The walling from D southwards had all been built upon rock, laid bare at low water of spring tides and backed up by reclamation when all the space from D northwards was open to seaward, so that owing to good foundations and no undue pressure being brought upon it, this part remained perfectly safe.

The part from C to D was the only part of the sea walling built, in which coffer-damming had been necessary.

The walling was finished to B. From B westwards, extended a pier belonging to the Harbour Defences Department, so that the reclamation gradually approaching pressed forward a large volume of harbour sludge, which hemmed in on every side became a daily accumulating, and though slow, was a moving, pressure of vast momentum concentrated on this part of the wall between B and D, which no ordinary structure could have withstood.

This wall, then, bodily slipped forward off its foundation, about 2 feet 9 inches at its central point, being held firm at its two ends by the adjacent walling like a flexible chain. It likewise turned over on its toe line from 1 in 6 to perpendicular.

To prevent further movement, a quantity of the sludge was taken out and thrown over on the seaside of the wall; the wall itself was backed up by barge loads of earth, the reclamation for the time being stopped.

This piece of walling had been founded by the Engineer at a depth of 6 feet below the surface upon soapy clay, while the solid rock was about 3 feet lower. It is difficult to understand, how this risk was run by a competent Engineer; it seems to be an instance of the vice inherent in departmental work.

WALLING AT C—.From C the walling was carried on under the Author's arrangements.

The great labor involved in building, with a high narrow staging intervening between the material and the work, was recognised by the Engineer in designing upon his contract drawings *Plate* XXII., a s[...] of wood, carried by the dam itself.

But the author looked upon the staging as a form which was being constantly undermined in digging for a foundation, and considered it would be an unjustifiable risk to place heavy machinery, such as steam cranes, upon it with so many lives underneath. There was also, either the extreme inconvenience in building, had it been strutted to that extent which would have rendered it safe, or the equally extreme insecurity from the almost destitute state of strutting as designed. It was, therefore, determined to substitute some method which would have all the advantages, without the disadvantages, of either side, or over-head, staging.

The contract sections supplied to the author showed a depth varying from 6 to 9 feet, and for this depth of excavation, the advantage to be derived in excavating by the lifting power of steam cranes could not be over estimated. Had the foundations been known to be deeper, full tide dams and staging would have been necessary, but the supposed moderate depth of the foundations did not warrant full tide dams.

To obtain the advantages of staging without its drawbacks, the expedient was adopted of building flat punts 50′ × 17′ × 4′ 3″, the construction of which is shown in *Plate* XXIII., upon which rails were laid for the stream cranes, forming broad useful floating platforms as well as stages. Perhaps a noticeable point about these flats was in the corner logs. Logs 16 inches square were cut diagonally and bolted to the frame timber as shown. From this point in their construction, they contrasted strongly with all the punts belonging to the company in stiffness, which stood them many a time in good stead when stranded in an unlucky place by careless boatmen.

*Steam Pile Driving.*—The author began his pile driving on the same principle as that of the company, with one difference. Instead of putting his piling engine for main piles at the end of his piling flat, he placed it upon rail pieces laid along the side, so that he was enabled to drive two or three main piles during one tide instead of only one: but before long, he found hand-piling very unsatisfactory.

On the south side of the basin, there was about 6 feet of wet soapy clay—one or two feet of dry, black clay resembling soil, immediately underneath which, a firm moorum foundation was obtained.

On the north side, beneath the dry black clay there was found to exist a stiff yellow clay of variable depth overlying the moorum or the rock, so that the progress with hand piling was slow.

Some spare plant was available consisting mainly of an open flat, and a 4 H. P. Horizontal Engine, and tubular boiler, neither specially applicable to piling; but by placing the engine upon a wagon body on rails on the flat, and dismantling two of the hand engines, a serviceable steam pile engine was obtained. The power was communicated through a winch end, round which two coils of light chain attached to the hammer were thrown each successive lift.

As the tide receded, this flat was carefully lined and the whole was managed by a fireman, a ship's caulker as foreman, and two or three Mahratta coolies.

*Taking out Foundation.*—The flats with the steam cranes were stranded on either side of the dam. The steam cranes lifted up the buckets loaded with clay, swung their jibs across the flats, tipping their load on the outside.

One practical disadvantage early showed itself under the action of the returning tide; the deposit sloped, and towards the dam, causing the flats to tilt inwards. This was remedied by the men clearing the deposit from near the boat just before the tide returned.

*Building.*—The flats developed many of their conveniences in building. Instead of a separate barge with wooden crane in which to load the ashlar, the steam crane was itself floated to the depôt, and the flat loaded with two rows of ashlar stone on each side, care being taken to keep the boat trimmed.

Their mobility in all other operations was of great importance. Two cranes uniting their power drew the piles singly, wrenched out the struts and walings as the building advanced, lifted the pumps, laid the composite structure of spare piles and ashlar stones to form a temporary platform for the advancing work, laid down on the platform the pumping engines and a small circular saw-bench behind. This saw-bench was convenient for cutting wedges, &c., &c., and was driven by the waste steam when the pumping was over.

*Pumping.*—Murray's chain pumps were substituted for centrifugal; these are invaluable for harbour work. They have no valves, develope a high duty, and can be repaired by a good blacksmith.

They have, however, two drawbacks. They are apt to be damaged by careless driving in starting, but their greatest fault is that they must have a well hole.

The two pumps employed were 12″ × 6″ discharge, were driven by two 10 H. P. Double cylinder Clayton and Shuttleworth's Portable Engine, of which the author cannot speak too highly.*

*Stage for Pumping Engine.*—With so small a range of tides in which foundations could be dug and built, to take advantage of every spring-tide was of great importance. This required the earliest possible translation forward of the pumping engines; so immediately on the masonry of the previous foundation being at level of neaps, a staging of spare piles and ashlar blocks was built at the end of the masonry to take advantage of the young springs.

*Building up pump-hole.*—This had to be done by a strong effort in one tide if possible.

*Belt connection between Engines and Pumps.*—In centrifugal pumps, the high velocity requires smooth tight leather belts, which, sent green from England, are frequently rotten, and often break; besides, unless housed in, were in the night time, from dew, and in the rainy season, constantly slipping off and by the time they were again adjusted, the pump had lost its "fang."

For the chain pumps, with their low velocity, the author constructed belts of 8 piles of canvas thoroughly soaked, and made into one solid riband with oil paint, and then stitched together in several lines by sail-makers. These belts stood well and from their sticky and oily nature neither dew nor rain displaced them.

* At the Worlee sewage outfall, Bombay, two pumps of equal theoretical discharge worked by two separate but similar and equal steam engines are placed a small distance apart.

The one pump is a Thomson's chain pump, as made by Moreland and Son, of a construction for large sizes even better than Murray's; a description of this kind of pump will be found in "Engineering" June 11th, 1869. the other a Gwynne's centrifugal. The result is curious, while the chain pump is not affected by the centrifugal, the latter is affected to half of its discharge by the chain pump. This was to have been expected and the Municipal Engineer made a mistake in placing side by side two pumps respectively typical of two opposite modes of action in mechanics.

The one is typical of the modern tendency in mechanics of gaining momentum by increase of Velocity, rather than by increase of Mass, as in the older School. The former may be supposed to be picking up single filaments of water rapidly. the latter to seize on a great number of filaments at short intervals of time; but at the end of one of these intervals, it carries off at once all the filaments within its reach.

A chain pump of course did not require fanging, but could always be set agoing at once on an undue accumulation of leakage.

*Depth of Foundations.*—Unfortunately the depths of rock foundation shown on the Engineer's contract section were accepted as correct.

This showed an average depth of 8 feet while it was necessary to drive the piles and dig the foundations a depth of 16 feet. The wood for the coffer-dams had been purchased 18 feet long, sufficiently long for 8 feet founds, but much too short for 16 feet deep founds.

As it may be interesting to note the ratio of increase of labor and depth, an extract from a computation to this effect is given in an Appendix.

It afterwards appeared that the depth of foundations had been obtained by borings, the apparatus consisting of a pointed iron rod 1 inch diameter driven by an 8 lb. hammer.

The author certainly believed that among all Engineers, but more especially among Hydraulic Engineers, the auger and special boring tools were always in use for ascertaining beforehand the depths necessary for foundations.

Borings are an important element in considering the outline, structure and expense of a proposed dock. Efficient borings were taken in 1868-69, but too late to be of any value. The reclamation had closed around the present determined outline of the dock, and the company by this time found that they were unable to complete their undertaking.

This confidence in an Engineer's carefulness was unfortunate. It was discovered that an Engineer's mistakes are among the legitimate risks a contractor must run, and that a company have a right to benefit by the mistakes of their Engineer as well as by his services.

The author meant to undertake a sketch of other works in some of which he was interested, and with the progress of others with which he was intimate—the approaches to the Reclamation, the drainage of the Reclamation, the roads upon the Reclamation,—but he has already outrun the limits of a goodly sized paper. What he has written, though the subject is wholly within the ordinary routine of Hydraulic Engineering, may prove suggestive.

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APPENDIX.—*Pumping for Excavation in half tide dams.*

The ratio in which the expense for *Pumping for Excavation* increases may be ascertained, as nearly as possible, in the following manner:—

Suppose that each tide the laborers can excavate about one foot in depth, the ratio of the expense of pumping can be thus represented—

| | | | | | | |
|---|---|---|---|---|---|---|
| First tide | One foot of water | pumped | One foot high, | .. | $= 1 \times 1 = 1^2$ |
| Second ,, | Two ,, | ,, | ,, Two | ,, | .. | $= 2 \times 2 = 2^2$ |
| Third ,, | Thee ,, | ,, | ,, Three | ,, | .. | $= 3 \times 3 = 3^2$ |
| Nth ,, | N | ,, | ,, N | ,, | .. | $= n \times n = n^2$ |

So that the total pumping of an excavation $n$ feet deep is represented by—

$$1^2 + 2^2 + 3^2 + 4^2 \ldots + n^2$$

In the present case, the value of this sum for the Section depths, and corresponding executed depths, for every ten feet, gave over all the proportion of 19 to 55. The ratio is not materially altered by a material addition to the quantity excavated each tide.

J. B. C.

# No. CCLXXXI.

## MANUFACTURE OF ARTIFICIAL STONE IN INDIA.

*Report on the result of certain experiments made on the manufacture of Cements and Artificial Stone.* BY E. C. PALMER, ESQ., C.E., *Exec. Engr., Baree Doab Canal, Punjab.*

*Processes.*—The following papers on the subject were used as a guide in the manufacture:—

Roorkee Professional Papers, May 1864.

General Pasley's Experiments on Cements.

*Materials.*—The materials obtainable at this place (Umritsur) are—

*Kunkur lime* of excellent quality, when used fresh and free of ashes.

*Kunkur* in nodules, of sizes varying from that which would not pass through a 4-inch ring to as small as a hazel nut.

*Stone* chippings or split pebbles of quartz, sand-stone, &c.; the uncalcined refuse of lime-kilns.

*Stone-lime.*—A good fat lime of average quality.

*Sand,* river-sand (not sharp grit).

*Clay* of various qualities.

The water used was river-water.

*Detail of experiments Nos. I. and II.*—These were prepared on the principle said to be that on which many artificial stones are successfully made, viz., mixing the materials with a very small quantity of water. It was, however, found impossible to get the materials to bind at all with one quart to the cubic foot of dry "Compo," and even double that

quantity, as applied in No. II., was quite insufficient. It seems probable that only under enormous pressure, as in the "Coignet system," would this proportion of water answer.

*Nos. III. and IV.*—These had a small proportion of iron-slag introduced in place of kunkur; the slag obtained from the Madhopoor Foundry was broken up to half inch; equal quantities of slag and kunkur were rammed together in a stout box, 2′ × 1′ × 1½′, with a limited amount of water; the boxes were buried 3 feet under ground, and a water-course, in which canal water flowed at intervals, was made over the hole, and the earth thus kept very moist; after two months they were taken out and examined.

*Result No. III.*—Was crumbly and quite useless as a block.

*No. IV.*—Was better, but much too friable; it should be mentioned that this (No. IV.) block, left on the surface of the ground out of its box, improved very much when looked at some two months afterwards and was nearly hard enough to be useful.

*No. V.*—This was to see if stone chippings would not prove a better material than kunkur; they were broken into sharp fragments, and strewed in, and rammed with the mortar mixed stiff, and buried in the same manner as Nos. III. and IV.

*Result.*—When examined two months afterwards it was fairly hard, but the fracture showed the sand had a mischievous effect on the binding qualities of the kunkur lime.

*No. VI.*—The only variation in the proceeding with this was the use of one-third stone lime and double the proportion of sand.

*Result.*—The sand again quite spoiled the block.

*No. VIII.*—This was an attempt to use larger nodules of kunkur, with the view of lessening cost. The large pieces 4 inches to 5 inches were laid in an even layer, packed up with smaller nodules, and then rammed with one-fourth their bulk of dry kunkur lime, and water sufficient to make it of the ordinary consistency of mortar. This was examined after being allowed to harden under ground for 6 weeks.

*Result.*—It was fairly hard and tough, but the fracture showed large interstices, imperfectly filled with mortar; indeed, wherever the larger pieces of kunkur had not been crushed by the pounding, the solidity of the block was seriously impaired.

*Nos. XI to XIV. Cement.*—These were a set of experiments made

with various clays following the process described by Mr. Price of Kurrachee in the Roorkee Papers, May 1864.

*Result.*—A quick setting mortar only was obtained.

*Nos. XV. to XVII.*—The same as the above four, using kunkur lime instead of stone lime.

*Result.*—These were certainly better than the first set, but still a long way from cement.

*No. XIX.*—Following General Pasley's process, using wet "Kahnowan" clay (bluish gray color) instead of Medway blue clay, and old stone-lime instead of chalk.

This set freely enough under water, but was not strong when it was thoroughly set.

*No. XX.*—The same as No. XIX., using fresh stone-lime and less of it, an ordinary quickly setting mortar was the result.

*No. XXI.*—The same using kunkur lime: a very excellent mortar, quick setting and strong, but nothing like cement.

*No. XXII.*—The same as No. XIX., using a very peculiar clay obtained from near Dhangoo, with the same result as No. XIX.

*No. XXIII.*—This, and the three following experiments, were made to obtain further information on the kunkur with kunkur lime blocks:—

1*st.* As to the proper proportion of kunkur lime.

2*nd.* What was the least amount of pounding necessary.

In a stout wooden case, $2' \times 2' \times 1'$, were pounded 6 cubic feet of kunkur and $2\frac{1}{2}$ cubic feet kunkur-lime, with a very moderate amount of water, the kunkur being previously well soaked in water; the pounding was finished in 14 hours, by two men with round-headed pestles weighing 11 fbs.

This was buried in its case in the ground, kept very moist with a water-course overflowing it on the 8th February; taken out and examined on the 8th March.

*Result.*—Sawn down through the middle it presented an admirable even structure, with rather more lime-joint than is necessary; the lime had not set perfectly, and the hardness of the mortar continued to increase for weeks after its exposure to the air, until the lime mortar joint was at least as hard as the kunkur nodule it enclosed, *i. e.*, in a fracture of any portion of the block, the kunkur was found broken, instead of being forced out of the cement.

*No. XXIV.*—In this, with 6 cubic feet of kunkur only, 2 cubic feet of kunkur lime were used. and the pounding only occupied 10 hours; buried on the 13th February, taken up 8th March.

*Result.*—Sawn down through the middle, it presented much the same section as XXIII.; indeed, no differenee can be detected in the two specimens.

*No. XXV.*—Continuing to decrease the lime, this had only 1·75 cubic feet to the 6 cubic feet of kunkur, and the pounding was confined to 8 hours; buried 17th February; taken out 8th March.

*Result.*—Its sawn section shows some empty interstices, into which the mortar has not penetrated, and where it is solid the nodules of kunkur appear too close together, suggestive of too small a quantity of lime, and insufficient ramming; notwithstanding these faults, it forms a very efficient block, and would be probably as serviceable for the apron of a Rapid as the best brick-work.

*No. XXVI.*—The mortar in this was reduced to 1·7 cubic feet, and the pounding to 7 hours; buried 19th February; taken up 8th March.

*Result.*—When first taken up, this was too green to bear sawing, but rapidly increased in hardness, and on being sawn through there is really but little to choose between it and XXIII.

*No. XXVI.*—The diminished quantity of lime-joint as compared with solid kunkur in the sawn section is apparent, but it does not affect its solidity; it is a better block than No. XXV., and this can only be explained on the supposition that the two coolies employed to ram it worked harder than those on No. XXV.

The next set of four experiments were made to determine—

*1st.* Whether there was any advantage in burying the fresh consolidated block in earth kept very moist.

*2nd.* The propriety of using large (4″) or small (1″) nodules of kunkur.

*3rd.* If an addition of one-fifth of stone lime to the kunkur lime would be of advantage.

*No. XXVII.*—To 6 cubic feet of small kunkur, were added 2 cubic feet of lime and half a cubic foot of stone lime, pounded in the usual way for 12 hours, and buried in ordinary earth (not moistened) on the 5th May; taken out 18th September.

*Result.*—Sawn in half, the consistence was excellent, but the mortar

was not thoroughly set (there had been a good deal of rain, and the earth it was buried in became unavoidably moist, though not wet); no perceptible advantage in the addition of stone lime.

*No. XXVIII.*—The only difference in the material in this is the use of large kunkur, and it was buried as No. XXVII. in dry earth on the 6th May; taken out 18th September.

*Result.*—I could not detect any difference; the sawn section showed the large nodules of kunkur well bedded; the mortar set, but had not nearly attained its ultimate hardness.

*No. XXIX.*—Precisely the same as the two last, No. XXIX. having large, and No. XXX. small kunkur, buried deep in earth kept constantly moist on the 8th May; taken out 18th September.

*Result.*—No difference worth recording was found between these and Nos. XXVII. and XXVIII., probably from the reason above given, that the soil in which the first two were buried was moistened by rain.

*No. XXXI.*—To 6 cubic feet of kunkur were added 4 measures of kunkur lime, 1 of stone lime and 1 of river sand, rammed in the usual way, and buried as Nos. XXVII. and XXVIII. on the 10th May; taken out 18th September.

*Result.*—The mortar-joints of these, like all those taken up 18th September, was not thoroughly hard, and until this ultimate hardness is attained, is difficult to judge correctly of the effect of the sand; at present, I can detect neither advantage nor disadvantage.

In order to show readily the proportions of materials used in each experiment, an Appendix A. is forwarded.

*General remarks.*—I may conclude this report with the deductions I have made from these experiments:—

*1st.*—That either for want of the proper materials, or to my not knowing how to use them, I cannot make anything worthy of the name of cement.

*2nd.*—That kunkur well washed, whether in small or large nodules, forms the best and cheapest material for the manufacture of concrete blocks.

*3rd.*—That kunkur lime, free of ash, fresh-burnt, using the kunkur that breaks with a gray fracture (not black), is the best binding material.

*4th.*—That the admixture of stone-lime has perhaps no advantage;

certainly no advantage commensurate with the increase of cost, its price being about five times that of kunkur lime.

*5th*.—That sand is mischievous.

*6th*.—That a cubical block 2 feet square and 1 foot deep requires two strong men to ram it with 11 lb. rammers for 7 hours; and that less is insufficient—*vide* experiment Nos. XXV. and XXVI.; below are given suggestions for reducing this labor.

*7th*.—That no advantage is gained by using less water than will make stiff mortar of the lime; more splashes out of the mould, while the kunkur absorbs one-fifth of its own weight.

*8th*.—That the advantage in burying the blocks lies only in the necessity of preventing the outside skin (the most important part) of the block drying before it can crystallize, and this could be effected by throwing a heap of sand over the block when taken out of the mould; after a month they should be uncovered and left for three months before being used in any position where they would be exposed to blows or attrition.

*Suggestions for the economical manufacture of the blocks*.—The kunkur well screened should be burned on the spot in quantities not exceeding four days' supply; it should be the gray kunkur which is found in sandy loam.

The kunkur for the block should be the black or rather dark-blue usually selected for metalling roads, carefully avoiding that form of it which is exceedingly corrugated, a compact nodule being the desideratum; after screening, it should be left in water until required for use.

Neither the kunkur nor the water should be used from localities where "kullur" (or "reh") abounds.

It is of the utmost importance that the outside or skin of the block be as hard and compact as possible; this cannot be effected when the concrete is consolidated in a wooden case.

The bottom and sides must be lined with some hard unyielding substance; cast iron of moderate thickness would probably be continually getting broken by the clumsy use of the pestle; slabs of slate have the same objection. I would, therefore, make the mould of stout slabs of *keekur* or *sheesum* wood, and line them with fine sheet iron or ½-inch boiler

plate. These plates, by a simple arrangement of wedging, could be easily released when the ramming was effected, as also the bottom. The wooden mould lifted off, and the block covered with sand at once, the mould and its lining would then be ready for another block.

A great saving would be effected in the ramming by adopting the principle used by druggists, viz., suspending the pestle from a spring, the contraction of which saves the labor of the lifting about 3-4ths the weight of the pestle.

The shoe of the pestle should be of cast-iron, rectangular in plan, and having only ½-inch play inside the cheeks of the mould.

*Cost of manufacture.*—The estimated cost of this manufacture on the line of the Baree Doab Canal between Aliwal and Vahn, for 4 cubic feet, *i. e.*, 2′ × 2′ × 1′ deep, is as follows:—

| | | | |
|---|---|---|---|
| 6 cubic feet of kunkur, at Rs. 4 per 100, .. .. | 0 | 3 | 11 |
| 1-8 cubic foot of kunkur lime, at Rs. 11 per 100, .. | 0 | 3 | 2 |
| 2 laborers, at 3 annas each, .. .. .. .. | 0 | 6 | 0 |
| 1000th part of cost of the mould and pestle, say Rs. 15, | 0 | 0 | 3 |
| For 4 cubic feet, .. | 0 | 13 | 4 |
| For 100 cubic feet, .. | 10 | 13 | 4 |

There may possibly be some localities where the cost of material would be 25 per cent. cheaper; but I have given fair average rates for general estimates.

*Weight and strength.*—The weight of one of these kunkur blocks is 163 lbs. per cubic foot.

The strength to resist crushing cannot be determined until sufficient time has elapsed for the blocks to attain their ultimate hardness.

E. C. P.

## APPENDIX. A.

*Experiments on Cements or Hydraulic Mortar and Artificial Stone.*

| No. of experiment. | Iron slag from foundry. | Kunkur, ½″. | Kunkur lime. | Stone, 1″ and smaller. | Sand, passed through a mill. | Stone lime, old. | Stone lime, new. | Clay, ordinary potter's. | Clay, Umritsur sample. | Clay, dry blue Kahnowan. | Clay, wet Kahnowan. | Water, quarters per cubic foot of compo. | Clay, Dhangoo white. | Kunkur, large 4″. | C. cement or S. stone. | Mode of manufacture. | Result. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I. | ... | 3 | 1 | ... | ... | ... | ... | ... | ... | ... | ... | 1 | ... | ... | S | Rammed in a box 2′ × 1′ × 1½′ in 3 layers, | Friable and useless. |
| II. | ... | 3 | 1 | ... | ... | ... | ... | ... | ... | ... | ... | 2 | ... | ... | S | Ditto; the water was not nearly sufficient, and more was added, ... ... ... | Ditto. |
| III. | 2 | 2 | 2 | ... | ... | ... | ... | ... | ... | ... | ... | 2 | ... | ... | S | Ditto, ditto, ... ... | Ditto. |
| IV. | 2 | 2 | 1 | ... | ... | ... | ... | ... | ... | ... | ... | 2 | ... | ... | S | Ditto, ditto, ... ... | Bad, but improved. |
| V. | ... | ... | 1 | 2 | 1 | ... | ... | ... | ... | ... | ... | 2 | ... | ... | C | Sand and lime first fixed, then stones strewed in, | Better, but useless. |
| VI. | ... | ... | 2 | 3 | 2 | ... | 1 | ... | ... | ... | ... | 2 | ... | ... | C | And well rammed in 3″ layers,... ... ... | Friable and sandy. |
| VIII. | ... | 4 | 2 | ... | ... | ... | ... | ... | ... | ... | ... | 1 | ... | 4 | S | Rammed together; more water added, ... | Not solid enough, but hard. |
| XI. | ... | ... | ... | ... | ... | ... | 5½ | 1 | ... | ... | ... | A | ... | ... | C | The clay and lime ground together in a hand-mill made into small bricks, dried, and burnt, | Failure. |
| XII. | ... | ... | ... | ... | ... | ... | 5½ | ... | 1 | ... | ... | A | ... | ... | C | | |
| XIII. | ... | ... | ... | ... | ... | ... | 5½ | ... | ... | 1 | ... | A | ... | ... | C | | |
| XIV. | ... | ... | ... | ... | ... | ... | 5½ | ... | ... | ... | 1 | A | ... | ... | C | | |
| XV. | ... | ... | 5½ | ... | ... | ... | ... | 1 | ... | ... | ... | A | ... | ... | C | | |
| XVI. | ... | ... | 5½ | ... | ... | ... | ... | ... | 1 | ... | ... | A | ... | ... | C | | |
| XVII. | ... | ... | 5½ | ... | ... | ... | ... | ... | ... | 1 | ... | A | ... | ... | C | | |
| XVIII. | ... | ... | 5½ | ... | ... | ... | ... | ... | ... | ... | W1 | A | ... | ... | C | | |
| XIX. | ... | ... | ... | ... | ... | W 4 | ... | ... | ... | ... | W5½ | ... | ... | ... | C | Following the process of General Pasley, R.E., who used the Medway clay with new lime, | |
| XX. | ... | ... | ... | ... | ... | ... | W1 | ... | ... | ... | W2 | ... | ... | ... | C | | |
| XXI. | ... | ... | W 1 | ... | ... | ... | ... | ... | ... | ... | W2 | ... | ... | ... | C | Ditto with lime which had been immersed in water for 24 hours, ... ... ... ... | |
| XXII. | ... | ... | ... | ... | ... | W 4 | ... | ... | ... | ... | ... | ... | W5½ | ... | C | | |

A—enough water to make stiff mortar; W—by weight.

APPENDIX A—*concluded.*

| No. of experiments. | Kunkur, large. | Kunkur small. | Kunkur lime. | Stone lime. | Small stones. | Mortar composed of kunkur lime 4 parts and stone lime 1 part. | Sand. | | Mode of manufacture. | Result. |
|---|---|---|---|---|---|---|---|---|---|---|
| XXIII. | ... | 6 | $2\frac{1}{2}$ | ... | ... | ... | ... | S | Pounded in layers in a box 2′ × 2′ × 1′ for 14 hours, | Excellent. |
| XXIV. | ... | 6 | 2 | ... | ... | ... | ... | S | Ditto, ditto, 10 „ ... | Ditto. |
| XXV. | ... | 6 | 1 7 | ... | ... | ... | ... | S | Ditto, ditto, 6 „ ... | Ditto. |
| XXVI. | ... | 6 | 1·7 | ... | ... | ... | ... | S | Ditto, ditto, 7 „ ... | Ditto. |
| XXVII. | 6 | ... | ... | ·6 | ... | 2 | ... | S | Pounded, gradually adding the materials, 12 „ ... | Ditto. |
| XXVIII. | ... | 6 | ... | ... | ... | 2 | ... | S | Ditto, ditto, ... | Ditto. |
| XXIX. | 6 | ... | ... | ... | ... | 2 | ... | S | Ditto, ditto, ... | Ditto. |
| XXX. | ... | 6 | ... | ... | ... | 2 | ... | S | Ditto, ditto, ... | Ditto. |
| XXXI. | 6 | ... | Parts 4 | Part 1 | ... | ... | 1 | S | Ditto, ditto, ... | Ditto. |
| XXXII | ... | 6 | 4 | 1 | ... | ... | 1 | S | Ditto, ditto, ... | Ditto. |

(Signed) E. C. PALMER,
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## *Report on the Manufacture of Ransome's Artificial Stone in Bombay*, 1869. BY A. PYE-SMITH, ESQ., C.E.

*Materials employed.*—In the manufacture of Ransome's Patent Stone there are four materials usually necessary, viz., silicate of soda, chloride of calcium, sand, and powdered limestone.

The two chemicals, silicate of soda, and chloride of calcium, were sent from England, having been obtained from Ransome's Works at East Greenwich and Ipswich. They arrived in Bombay in 1868, in a state fit for use.

The limestone required was easily found in Porebunder stone.

The sand required must be siliceous, clean, sharp, and of a good color. The only sands found near to Bombay are formed of either black, disintegrated basaltic rock, or of broken shells, neither of which are suitable for making stone. I have visited various places in this Presidency in search of a good sand. This is to be found in most parts of Guzerat, but the cost of carriage to Bombay would probably be found greater than similar sand can be got from Cutch. In Sind, I found several sorts of good sand, especially some of various colors, white, yellow, and red, 40 miles inland, near to Jungshai. Some of this was sent to Bombay, and has been used. I also visited the whole of the coast of Kattywar, but met with only shell and black sands; but, in Cutch, I found in dunes along the coast a fine, clean, sharp sand of a good color, which I have used as the ordinary material for the stone. The cost is at present Rs. 22 per bras delivered. I have also used a coarser sand obtained from ships in ballast, brought from various parts, such as Kurrachee, Mandavee, &c. This is used in conjunction with the finer kind, and costs about Rs. 6½ per bras delivered.

*Works and Plant.*—The plant required for the manufacture is simple. An estimate of Rs. 16,620 for temporary works was sanctioned by Government in 1868, the site being selected, and the work executed by the Executive Engineer for Reclamations, Captain Ducat, whose previous experiments in making Ransome's stone specially interested him in the undertaking.

The expenditure on account of plant was Rs. 13,868-11-8, exclusive of two pug-mills which had been sent from England.

A supplementary estimate of Rs. 750 was sanctioned for an air pump, which it was expected would have reached Bombay about August last, but it has not yet come.

*Labor employed.*—Small works can ill bear the cost of an establish-

ment, but being unable to obtain any overseer from the Public Works Department, I endeavoured to get a good man in the open market. In this I was not very successful until I engaged Mr. T. A. Shaw in July, who has proved himself very efficient. The bulk of the labor is done by coolies and boys, whom, it is almost needless to say, I had to teach the arts of moulding, &c., myself. I had, at first, much difficulty in getting plaster mould makers; the few men in Bombay being engaged with Mr. Kipling, or elsewhere. The cost of moulders was, therefore, higher than it is now.

*Work done.*—Operations were commenced in April with Sind sand, and before all the plant was erected. The sand from Cutch arrived in June, but work did not fairly commence till July. In July and August, a good deal of stone was made that turned out useless. Besides bad workmanship, there were some accidents, which told heavily against the total outturn, small in itself. But by September, I had got all the men into a regular way of working, and had corrected defects in the plant, or in my arrangements.

The nature of the stone manufactured has been mostly architectural, for the new Secretariat, the new Post Office, and the Surat High School, such as cornices, quoins, bases, shafts, and capitals of columns, arches, and mullions. The color has been chiefly a white faintly tinted with grey; but in some cases, buff, yellow, and red have been used. The white stone has the appearance of Portland stone, and cannot easily be distinguished from it. Grindstones have also been made, which have given great satisfaction, being far more equal in texture and quicker in cutting, than Newcastle stones.

*Strength of the stone.*—I have broken bars of the stone with the following results. I have added the strength of some natural stones, reduced, when necessary, to the same sizes for comparison.

| Scantling 3″ × 3″ : 1′ 10″ clear between supports. | Breaking weight in lbs. | Constant in cwt. |
|---|---|---|
| Ransome's stone made in Bombay—mean of 7 experiments, viz., 809, 769, 794, 764, 769, 769, 882 lbs. | 793 | ·480 |
| Porebunder stone—2 specimens from Colonel Fuller, 663, 664 lbs. ... ... ... ... ... ... | 663½ | ·402 |
| Porebunder stone—ordinary specimens from Scott, McClelland, and Co., 660, 621, ... ... ... | 640½ | ·388 |
| English Bath stone, ... ... ... ... ... | 280 | ·175 |
| Do. Portland stone, ... ... ... .. ... | 224 | ·141 |
| Do. do. do., Australian experiments, ... | 616 | ·375 |

*Supply of finished stone.*—During the monsoon the stone was washed free from the chloride of sodium formed within it by the natural rain. Since the rains ceased, an artificial stream has been used, but, in consequence of the increasing requirements of water in the Reclamation works, the supply to the branch pipe to the stone works has been curtailed. A larger main is now, however, laid, which will supply both works properly. Delay in sending off finished stone has arisen during the last few weeks by the frequent partial or complete shutting off of the Vehar water pipe.

*Cost of the Stone.*—So little was done up to the 30th June, that no cost rate of the stone can be determined before July, when I first had a proper overseer.

In the months of July and August, the financial results were very poor, showing a cost of Rs. 7-10-11, and Rs. 10-14-3, per cubic foot, respectively, partly on account of the small orders for stones received, but chiefly on account of stone badly made. The faulty stone produced in these months was partly included in the following month of September, which shows a cost of Rs. 9-14-1 per foot in consequence. But in September itself, there was very little wastage, and less still in October, so that the rate returned for the latter is Rs. 5-0-8, and the true rate for September would be Rs. 4-11-7.

In October, there were a few extra expenses, which, small in themselves, tell at once in an affair on a small scale; and as we are likely to improve as we go on, I think Rs. 5 will prove the maximum rate. The details of this amount in October are as follows :—

| | RS. | A. | P. |
|---|---|---|---|
| Moulds, .. .. .. .. .. | 0 | 6 | 8 |
| Labor, .. .. .. .. .. | 0 | 11 | 2 |
| Establishment, .. .. .. .. | 0 | 3 | 8 |
| Repairs, &c., to plant, .. .. .. | 0 | 1 | 11 |
| Petty stores, .. .. .. .. | 0 | 3 | 5 |
| Silicate of soda, .. .. .. .. | 1 | 9 | 5 |
| Chloride of calcium, .. .. .. .. | 1 | 6 | 8 |
| Sand, .. .. .. .. .. | 0 | 5 | 9 |
| Per cubic foot, .. Rs. | 5 | 0 | 8 |

and in September, leaving out of count the losses properly debitable to the preceding months, the following :—

| | | | | | RS. | A. | P. |
|---|---|---|---|---|---|---|---|
| Labor, | .. | .. | .. | .. | 0 | 11 | 8 |
| Establishment, | .. | .. | .. | .. | 0 | 4 | 9 |
| Repair to plant, | .. | .. | .. | .. | 0 | 1 | 3 |
| Petty stores, | .. | .. | .. | .. | 0 | 1 | 8 |
| Moulds, | .. | .. | .. | .. | 0 | 10 | 2 |
| Silicate of soda, | .. | .. | .. | .. | 1 | 6 | 6 |
| Chloride of calcium, | .. | .. | .. | .. | 1 | 4 | 0 |
| Sand, | .. | .. | .. | .. | 0 | 3 | 7 |
| | | Per cubic foot, | .. | Rs. | 4 | 11 | 7 |

Now the rates for silicate and calcium are in the preceding accounts taken from the supply bought from Ransome in 1868. It was at the time well understood, and I have Mr. Ransome's frequent assurances to the same effect since, that the rates at which he then supplied these chemicals were no criterion of their future or market price. I am not a party to the special arrangement then made with the Secretary of State, but I know that the chloride of calcium, or muriate of lime, is readily obtained from Alkali works, where it is a waste product, and that the silicate of soda may be easily manufactured here.

The cost of this calcium has been about Rs. 165 per ton delivered in Bombay, partly owing to the unnecessarily expensive packages it was sent in; but I can see no reason why it should be any more than Rs. 60, and, with good arrangements, it might be less.

The cost of the silicate has been Rs. 1-12-0 per gallon in Bombay. This has been made up thus :—

| | | | | RS. | A. | P. |
|---|---|---|---|---|---|---|
| Price in London per gallon, | .. | .. | .. | 1 | 0 | 0 |
| Freight, package, &c., net, | .. | .. | .. | 0 | 12 | 0 |
| | Per cubic foot, | .. | Rs. | 1 | 12 | 0 |

In this silicate of soda, 58 per cent. of the total quantity is water, and 66 per cent. of the remainder is silex, so that the cost of carriage is incurred unnecessarily for 86 per cent. of the material. The packing of solid caustic soda would be much cheaper than that of the silicate; but, even at the same rate, the charges on a quantity of soda, sufficient to make 1 gallon of silicate, would be only 1 anna 9 pies, instead of 12 annas as above.

Although the plant that would be required for the manufacture of caustic alkali, or of calcium out here, would be too extensive to make it desirable, if no other object than the Ransome's stones were in view, yet

there is nothing to prevent the manufacture of silicate here by importing the soda, when I estimate its cost would be as follows :—

| | AS. | P. | |
|---|---|---|---|
| Soda, at per cwt., ... ... ... | 6 | 10 | per gallon silicate. |
| Flints, at Rs. 7 per ton, ... ... ... | 0 | 2 | |
| Labor, ... ... ... ... | 0 | 8 | |
| Coals, &c., ... ... ... ... | 2 | 0 | |
| | 9 | 8 | |
| ·885 gallon per cubic foot of stone, ... | 8 | 6 | per cubic foot. |

Taking the above prices, the amounts for the month of October will be As. 8-3 for calcium, and As. 8-6 for silicate, or a reduction of Rs. 1-15-4 from the total of Rs. 5-0-8, making Rs. 3-1-8. Similarly, in September, the rate would be reduced to Rs. 2-15-10¼.

There can be no doubt that in work on a larger scale, the cost of several items, such as establishment, would be very much reduced, but without allowing anything on that head, or for any future improvements, the cost may be taken from these two months at an average of Rs. 3-0-7 per foot.

It is of very little consequence whether the stone made is perfectly plain, or elaborately moulded; it therefore appears that, other things being equal, the patent stone will prove more economical than any natural stone that would cost more than Rs. 3-0-7, while it must yield to natural stone when the cost of the latter would be less than that sum.

*The future in Bombay.*—Should the foregoing results be considered sufficiently favorable to justify the Bombay Government in carrying on the works on a larger scale in this town, the plant and buildings required would not be very expensive, as but slight additions to the former would be necessary. A situation close to the sea, for facilities of landing stores, and where there is room for stowing sand and chemicals, &c., should be selected; and I roughly estimate the cost of works for making, say 150 to 200 tons of finished stone, per month, as follows :—

| | | |
|---|---|---|
| Shed, 120′ × 40′, ... ... ... | Rs. | 3,600 |
| Office and dwelling for Foreman, &c., ... ... | ,, | 1,500 |
| Steam engine and gearing,... ... ... | Rs. | 3,500 |
| Boiler, ... ... ... ... | ,, | 2,000 |
| Disintegrator, ... ... ... ... | ,, | 1,200 |
| Traveller, tanks, saturating, and washing apparatus, benches, trucks, pumps, fixing machinery, &c., ... | ,, | 7,160 |
| Vehar water piping, say, ... ... ... | ,, | 1,000 |
| Contingencies, ... ... ... ... | ,, | 998 |
| | ,, | 20,958 |
| Value of old plant left at Moody Bay, say, ... | ,, | 3,000 |
| Total Rupees, .. | | 17,958 |

*Silicate-making plant.*

| | | |
|---|---|---|
| 3 Digesters and fixing, ... ... ... | Rs. | 5,000 |
| Evaporating pans, ... ... ... | „ | 750 |
| Sittling and stock pans, ... ... ... | „ | 190 |
| Shed for caustic soda, ... ... ... | „ | 500 |
| Contingencies, .. ... ... ... | „ | 322 |
| | Rs. | 6,762 |
| Workshop and plant, ... ... ... | „ | 17,958 |
| Total Rupees, ... | | 24,720 |

If, at any time, a greater quantity of stone were required, it could be made by simply adding more tanks for boiling, more washing troughs, and a small shed for extra moulders.

When the full strength of the works is not required for producing stones for Government purposes, it would increase their economic success and be a great advantage to the public, if indents were executed for private persons; for, although by very careful selection, the Porebunder stone used in Government buildings may be of a fair description, that generally accessible to builders in Bombay is, besides being small, very bad, both in appearance and in powers of endurance.

*In other parts of India.*—It is admitted that in some respects Bombay offers the least advantages in the use of artifical stone of any building part of India. Here wages are higher than elsewhere; and sand, the staple of the manufacture, is not to be found in the neighbourhood, but has to be brought long distances, while its rival, natural freestone, is plentiful and very cheap.

In most parts of India, either no stone is met with, or what there is, is too hard to be used for many purposes. In Madras and Bengal, for example, I believe there is scarcely any stone found, but there is an abundance of first rate sand, and it would seem that the Ransome's stone would be of extraordinary advantage in those Presidencies.

*Portable works for Up-country.*—There are many districts where stone is much wanted, but not in sufficiently large quantity, or delicacy of moulding, to admit of the erection of works, as at Bombay. I would suggest that, for these cases, portable works should be equipped, capable of producing comparatively plain stone. For instance, in Guzerat, such works would, I believe, be found very successful. Choosing some convenient railway or sea-board station for head-quarters and storing of the chemicals, the plan should be carried to one of the beds of rivers near where

a bridge, culverts, &c., were wanted. Temporary sheds would be erected of bamboos; the saturating pressure tank placed on the elevated bank; and water drawn for washing the stone from the river bed. Sand would be ready all around, and the quantity of arch and other stone required in the neighbourhood having been made, the works would proceed to the next centre of supply.

No steam power would be required, and as no delicate moulded work would be wanted, the making of moulds, and training of moulders, would not give any trouble. The moulds, indeed, might all be made at head-quarters. The following is the plant necessary for such work:—

2 Pugmills to woık by hand.
1 Pıessure chamber.
2 Pairs of small shear legs with Weston's blocks.
6 Small trucks.
3 Norton's tube pumps.
1 Force pump.
12 to 205′ Abyssinian tanks.
12 4′ Abyssinian tanks cut in halves.
Planks for moulding, benches, utensils, &c.

And I suppose the whole might be removed in about 50 bullock carts.

*Uses of the stone.*—Ransome's patent stone may be used for a great variety of purposes. For architectural mouldings it is chiefly suitable. For capitals, and other carved work, it may be cast with all the mouldings, neck, abacus, &c., true and finished, while the carving itself is roughed out and made ready to receive the fancies of the stone-cutter. Large homogeneous blocks may also be produced for statues, vases, or other sculptured work. In many cases, hollow blocks of a smaller size for building purposes are very advantageous. These may be so arranged as to form a solid, immovable wall, without any cement whatever. Grindstones made of Ransome's stone are astonishingly good and quick in action. For chemical purposes, as battery cells, slabs, &c., by a modification of the materials used, the stone is well adapted. For filters, especially such as are fixed in cisterns, the stone is, I think, unequalled. In the country, the following purposes may, in addition, be served:—River and other dams, bonded blocks made hollow and filled with concrete; all kinds of irrigation and canal works; bridges and culverts; and, in some cases, trams for roads. In fact, it is capable of taking the place of natural stone and bricks in any form.

(Signed) A. P.-S.

MOODY BAY, BOMBAY, 26*th November*, 1869.

*Memo. by* MAJOR-GENERAL TREMENHEERE, R.E., *Chief Engineer.*

Mr. Pye-Smith states that the total expenditure in cash and stock amounts to Rs. 27,005, and that 3,174¼ cubic feet of stone have been turned out, which gives a rate of Rs. 8½ per cubic foot.

I understand that Mr. Pye-Smith's salary is paid by the Secretary of State to Messrs. Ransome, who forward it. I am not aware what amount should be added to the charges upon this account. Mr. Pye-Smith arrived in Bombay in the month of January 1868; he has also travelled on duty in Sind, Cutch, Kattiawar, and Goozerat, and I conclude there have been expenses incurred, of which I have no information.

In the year 1863, 261 casks, containing 13,501 gallons of silicate of soda, and 94 tons (391 casks) of chloride of calcium, were received from England at a cost of Rs. 34,945-12-0. In 1868, a further supply (nearly the whole of the first being still unused) of 667 casks, containing 10,000 gallons of silicate, and 120 tons (891 casks) of calcium, was received, at a cost of Rs. 37,341.

Mr. Pye-Smith had of course to meet with several difficulties in the commencement of his operations, but has shown great intelligence and energy throughout, and has now, I believe, overcome all his practical difficulties.

In his report, he states that Rs. 5 per cubic foot will, he believes, henceforth prove the maximum cost of the manufactured stone. Comparing this with the rates given by himself for Porebunder stone (rates which Lieut.-Colonel Fuller states to be much too high) it is evident that, with the exception of two items, the manufactured stone cannot compete, as regards price, with the natural stone procurable in the market.

It possesses no advantage over the natural stone in appearance.

Lieut.-Colonel Fuller writes as follows:—

"I have come to the conclusion I always held, that Ransome's patent stone, however perfect the establishment and the plant may be, can never compete, under ordinary circumstances, with our local Porebunder stone, or in plain work, such as columns, with our Coorla basalt.

"It is true that carved foliage would be, if Mr. Pye-Smith's sanguine expectations be realized, eventually turned out cheaper, than if cut in Porebunder stone; but, taking the present out-turn rate of the patent stone, viz., Rs. 5, there is no advantage gained. The carved dressings in a building give a very small quantity of work in comparison with geo-

metrical moulded work, and the latter could be done in Porebunder stone, in most instances, at less than Rs. 3 per cubic foot."

He adds:—

"The process of manufacture is tedious, and washing out the chloride of sodium, or the salt formed by the combination of the chemicals, is a matter of time, and, if not very carefully done, the stone disintegrates (one stone has already disintegrated at the Post Office, and will have to be renewed). I am, therefore, of opinion, that a properly trained practical man in charge of the work is essential to success, and that it would not answer for Government to start their own works, with simply an overseer in charge. Manufactories, departmentally conducted, are seldom successful in a financial point of view, and I would decidedly recommend Government not to attempt to establish a manufactory of their own in any district. I would suggest that Messrs. Ransome & Co. be invited to set up a manufactory in a district like Guzerat, for instance, and agree to supply the patent stone at a given rate for a term of years; there would then be a chance of financial success, but not otherwise, in a country like this, where, in the event of any casualty happening to a trained manager, the work would necessarily come to a stand-still.

"Up to the present date, the Post Office, and small portion of the cornice of the Secretariat, have had to bear the cost of the patent stone, at the rates enumerated below,* and I request an early decision on the subject, pending which, I must continue to place work in Mr. Pye-Smith's hands. I was in hopes that the patent stone would enable me to build faster than if I had used Porebunder stone, but I regret to report that the Post Office has been considerably delayed thereby from the very commencement. It is true Mr. Pye-Smith explains this delay partially as due to Vehar water being cut off, but such a casualty is of frequent occurrence in Bombay."

It would appear from Mr. Pye-Smith's report that, if Government have not been put to a very unnecessary expense in the supply of the materials sent from England, they could have been sent out, or can be so, at a far less cost. The chloride of calcium is a waste product. He

* Viz.:—

| | | | | |
|---|---|---|---|---|
| May, | ... ... ... ... ... Rs. | 30 | 5 | 1 |
| June, | ... ... ... ... ... „ | 13 | 4 | 9 |
| July, | ... ... ... ... ... „ | 7 | 10 | 11 |
| August, | ... ... ... ... ... „ | 10 | 14 | 3 |
| September, | ... ... ... ... ... „ | 9 | 14 | 1½ |

states that silicate of soda, 58 per cent. of the total being water, can be readily made here, by importing caustic soda, and anticipates a consequent reduction in the cost of the stone, amounting to Rs. 2 per cubic foot.

These statements, which I believe to be well founded, appear to afford satisfactory and very valid reasons why such manufactures should not be carried on by Government, but be left to private companies, who, in their own interests, will make the most economical arrangements for prosecuting them.

*Bombay*, *January*, 1870.

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# No. CCLXXXII.

## CONCRETE IN ARCHES.

*Report on the Strength of an Experimental Concrete Arch made at Loodiana, Punjab.* BY J. E. TANNER, ESQ., M. I. C. E.

I FORWARD a report on the construction, testing, and breaking up of the concrete arch constructed in February 1869, and to preface the same with some remarks on consolidated concrete generally, the manner of mixing the mortar used, &c., &c., which seem in a manner required, as such relate to the concrete employed in the construction of the arch.

The concrete consisted of small material, that is to say, instead of breaking the bricks to a size that would pass through a $2\frac{1}{2}$ inch ring, as is the usual practice, it was broken small enough to pass through a ring $\frac{3}{4}$ of an inch in diameter. The advantage that seems offered, by using smaller brick or stones, instead of large ones, is that large stones are apt to get one on the other; when, however heavy a rammer may be, its weight, unless it is heavy enough to break the stones, does not consolidate the mass in the least, and there are, however carefully ordinary concrete may be put together, large interstices filled with loose mortar and air (as is seen in any old concrete-work that is demolished) and the mass is prevented from setting as solid as it would, were there interstices prevented from forming; by using small material, these interstices are prevented.

Experiments were made by me in 1859, to test whether such was not the best way of getting the greatest strength out of the material used; and though these experiments more than came up to my expectations of

increased strength, the matter was laid aside owing to the employment of concrete instead of brick-work no longer existing. But in 1863 being in charge of the Sutlej Bridge, I further experimented upon it.

The question of mortar was of course the first problem to be solved, but in India, at all events in the Punjab, we have not different quarries to choose from; there is fat or white lime useless for heavy work almost, unless it can be made hydraulic, and there is kunkur lime, which by itself does not make a first class mortar in the general way; though from analysis of many specimens, I quite believe that quarries may exist, from eminently hydraulic lime to rubbish. that cannot be used as mortar at all, owing to the amount of clay and sand mixed with the small quantity of lime in it. In a rough way, kunkur may be considered to hold six of sand and clay, to four of lime, which in the usually recognized list of mortars brings it under the head of puzzuolana, and as such, it works most admirably with the fat lime. Its addition by fractions up to one of fat lime increases in strength till one to one is reached, and from that point it gradually diminishes in strength, and as one of kunkur lime added to one of fat lime sets perfectly hard in 30 hours, we could not wish for a better lime for any work. Its price may be grumbled at, but if its entire strength is not wanted, it can be diluted with one of the fine sand generally procurable in most parts, without injuring its adhesive properties very much, and the addition of the sand has wonderfully decreased its cost. Such was the mortar used in all my experiments, treating the kunkur lime exactly as a puzzuolana by grinding it (dry) before it was mixed with the fat lime.

All my experiments went to show that the stronger a particular class of concrete was wished to be, the more it had to be consolidated, and the more it has to be consolidated the less water was required; thus—

| 1—Fat lime. | 1—Kunkur lime. | 3—Sand. | 4—Brick. | Age 30 days. | Consolidated to equal 170 per foot, (lbs.) | R = 300 |
|---|---|---|---|---|---|---|
| | | | | | „ „ 120 „ | R = 166 |

The prisms for trial were made 2 inches wide, 2 inches deep and 12 inches long, and were broken over supports 4 inches apart. The value of R was calculated by the formula given below. W = the weight on the knife of the breaking down machine, B = width, D = depth, L = length between support, $a$ = weight of the prism between supports.

$$W = \frac{2}{3} R \frac{B \times D}{L} - \frac{a}{2}$$

I give the value of some of the mortars at 20 days, 60 days and four years; it will be seen how the fat lime from the small size of the prisms has increased in value, while the kunkur lime has fallen off, and of the different concretes at 15 days, 30 days, &c., those at 30 days are the most interesting to an Engineer, as then his work ought to stand without any further looking after, but every day of age must add to the strength when good mortar has been used.

As a reference to the value that R represents, it may be remarked that in best London stock bricks R = 213.

Mortar prisms 2″ × 2″ × ·12″

| | Age 20 days. | Age 60 days. | Age 4 years. |
|---|---|---|---|
| Fat lime, ... ... ... ... | R = 74 | R = 158 | R = 787 |
| One fat lime and one kunkur lime, | R = 134 | R = 238 | R = 345 |
| Kunkur lime, ... ... ... | R = 60 | R = 128 | R = 45 |

Concrete prisms 2″ × 2″ × 12″

| Fat lime. | K. lime. | Brick. | Sand. | Soorkee. | Value of R. | At 15 days. | At 30 days | At 1 year. | At 4 years. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | ... | ... | R | 324 | 491 | 548 | 780 |
| 1 | 1 | 2 | 1 | ... | R | 146 | 166 | 305 | 450 |
| 1 | 1 | 3 | ... | ... | R | 150 | 180 | 287 | 345 |
| 1 | 1 | ... | ... | 3 | R | 143 | ... | ... | 427 |

The above prisms of concrete were all consolidated to weigh exactly 120 lbs. per cubic foot, which I found was the weight that concrete could be consolidated by rammers after the manner of metalling a kunkur road. At the end of my experiments, which comprehended upwards of 110 different proportions of materials for concrete, I was fully convinced from the strength, uniformness of texture throughout, and from the concrete not shrinking in the cast after it was taken from the mould, that there was no reason why an arch should not be made of it. To test whether it would answer, I made one 12 feet span, 14 inches wide, segmental, giving

a rise of 14 inches, and 6 inches for the depth at the key; the abutments were 16 inches long and 14 inches wide, while it was all carried up to the same height as the extrados of the key. Thirty days after completion 21 men stood on it; but as it did not move and I wished it to be broken, they were told to jump on it and it broke, disclosing the fact that the separate layers had laminated, and that the whole arch was composed of layers about three-fourths of an inch in thickness; yet notwithstanding it was composed of a series of layers, it was strong enough when thirty days old, to carry more than a crowd of men as a dead weight, light as the arch was for the rise given. I saw that the fault of the layers not having joined themselves into one mass was owing to the quantity of water I had allowed being too little; therefore I tried making blocks 2 feet by 2 feet and 1 foot thick, and there was no trouble in getting the whole to set in one mass; if the concrete is too dry, sprinkle water over it sparingly, for it wants but little; if it is too wet, sprinkle a little dry brick gravel over it. But to tell on paper the exact consistency that it ought to have is impossible; practice alone can determine it. It ought to have a quick-sandy motion when it is consolidated, but only just ought to be so. Any one who wishes to use the concrete can find out easily, by making two or three blocks not less than 2 feet by 2 feet by one foot thick.

In making the concrete on a large scale, a pug-mill should be used to mix the mortar, and as much of the sand and brick gravel as will allow the pug-mill to work; but as the concrete stuff is dry, comparatively speaking, when it goes into the work until it is consolidated, a pug-mill could not do the last mixing or so. In all the small work where I have used the concrete, the mixing has been done by hand; but in large works something else must be devised, such as a cylinder revolving horizontally at a slight angle, with 3 or 4 slight projections on the interior as ribs. I have seen such a machine used for mixing concrete in France. The brick gravel would be broken to the correct size without the necessity of screening it afterwards, by such a machine as is in use for breaking oil cake.

The strength of concrete in England is generally estimated to have a value for R of 100. Why consolidated concrete should have such a greater value than any concrete of which there is any record, I do not know, unless it is for the same reason that mortar sets better and has more adhesion under a fairly heavy weight, owing to the air being driven

out, which, but for the weight, would have remained in the joint and mortar.

*Memorandum of price of material, &c.*—Of course the price of small work ought to be considerably in excess of what the cost would be in large works, where proper appliances for breaking up the brick, grinding the kunkur and mixing would be supplied. What information I can give on the subject will be only to state what machines would most likely be found the best adapted to the work.

For grinding the kunkur, a cement mill, such as is in ordinary use for the purpose at home, may be worked either by a steam engine or bullocks. It will grind 300 lbs. in 5 minutes, while a coolie can hardly grind 80 lbs. per day. The price of kunkur will vary in different places, and it might pay better to grind the kunkur by steam, where it could be procured cheaply, and cart it to the work.

The cost of white or fat lime, which is one of the principal items in the cost, will of course vary according to the distance from the hills.

The cost of bricks need not be heavy; for so long as they are fairly burnt, their shape is not of any importance, but as fuel is now not only dear, but is also scarce, I should recommend the brick-rubbish procurable from the Sirhind ruins; the bricks, although now broken, are all perfectly well burnt, and could, I fancy be procured for so little at Sirhind, that it would well repay the expense of carriage; if past through rollers such as are used to break up oil-cake, (I believe some such machine has been patented in Calcutta for making soorkhee), the quantity that could be broken up by one bullock power per day would be out of all proportion to the cost of breaking by hand; besides, as the two iollers would be a certain distance apart, there would be a certainty of no large pieces, and the necessity for screening would be done away with.

The sand should be as coarse as can conveniently be procured. Ordinary loamy soil, such as is used for making bricks, is better than fine drift sand. But where brick is not very expensive, it would be better to use an extra quantity of brick instead of sand.

*Mixing the concrete.*—The paste of fat lime can be mixed with the kunkur lime (dry) in a pug-mill, and certainly one measure of the brick gravel (wetted); after that, I think a further addition of brick gravel would render it too stiff for the mill to work, and I should recommend a wooden or iron cylinder 3 feet diameter with 3 or more ribs in it and

about 12 feet long; made to revolve slowly and placed, not horizontally, but at an angle which would be determined by noting the greatest angle that would mix the concrete. The proportion of the mortar from the pug-mill and the extra brick gravel being thrown into the hopper together at the upper end, will be found properly mixed after it has past through the cylinder, and can be collected by each coolie in his own basket as the cylinder delivers it. A one horse pug-mill will make 600 cubic feet in 10 hours; how much such a cylinder would mix I could not say, but it certainly would mix quite 600 feet and most likely would mix for two mills.

The rammers used were the iron ones in use by the Department Public Works for metalling the roads; square ones of equal weight were made in wood to consolidate the corners and the edges near the mould.

Any planking will do for the mould, so long as the edges fit. It has been proposed by Mr. Kirby, Assistant Engineer, that the outside of the work should be vermiculated; and such certainly would be the best way of finishing off the outside, for it would give a good finish to the work and any little faults in the mould would not show.

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*Report on the construction and testing of a Concrete Arch built at Loodianah, in February* 1869.

Span 45 feet, consisting of an arc of 60°, depth at key 3 feet, 10 feet wide, abutments each 10 feet in length, or a total length of 65 feet on the face over all.

The concrete was composed of one part of white or fat lime, measured wet, *i. e.*, consistency of mortar, one part of ground kunkur lime measured dry, one part of sand measured dry, and two parts of bricks broken to the size of small gravel, which was wetted well before being measured.

The cost was as follows:—

| | | RS. | A. | P. |
|---|---|---|---|---|
| 860 | Maunds of white lime, at Rs. 45 per 100 maunds ... ... | 387 | 0 | 0 |
| 1260 | Ditto of kunkur lime 18 ditto .. .. .. | 226 | 12 | 9 |
| | Cartage of ditto ditto ditto .. .. .. | 24 | 0 | 0 |
| | Grinding ditto ditto ditto .. .. .. | 36 | 2 | 0 |
| 2560 | Brick gravel broken to size of small gravel, at Rs. 5 per 100 | 128 | 0 | 0 |
| 1260 | Feet of sand, at Rs. 2 per 100 .. .. .. .. .. .. .. | 25 | 3 | 2 |
| 207 | Water-carriers and beldars to mix concrete, at 3 annas each | 38 | 13 | 0 |
| 520 | Coolies, at 2 annas 6 pie each .. .. .. .. .. .. .. | 81 | 4 | 0 |
| | Baskets, hire of rammers and grind-stones, &c. .. .. .. | 9 | 10 | 4 |
| 1 | Head Mistree .. .. .. .. .. .. .. .. .. .. .. | 12 | 0 | 0 |

| | | Rs. | A. | P. |
|---|---|---|---|---|
| Brought forward, | .. .. | 968 | 13 | 3 |
| Cost of concrete | .. | 968 | 13 | 3 |
| Making centre and carriage of the material necessary | .. | 51 | 12 | 0 |
| Cost of striking centre and removing it | .. .. .. .. .. | 9 | 2 | 0 |
| | | 1,029 | 11 | 4 |

The total quantity of [illegible]ncrete in arch when it was consolidated was 4025 cubic feet; which compare[illegible]inst the quantity, 6290 cubic feet, as measured loose, while mixing shows [illegible] the consolidation required 60 per cent., and the cost of the concrete in place [illegible] 24-1-1½ per 100 cubic feet.

The arch took 24 days to build including abutments an[illegible]tions. When the centre was struck, 44 days after completion, no subsidence whatever was to be detected.

Three months after completion, the 45 feet, *i. e.*, the portion above span was loaded evenly with sun-dried bricks to 100 tons, just as the last bricks were being placed, the arch started, giving the cracks shown in diagram.

It was left with this weight on it for 20 days, when there being no signs of the cracks enlarging an extra weight was added in the centre, by building up a solid block 10′ × 10′ till it was equal to 41 tons, when the arch again gave with a similar start to that which it had given when the 100 tons had been placed on it; making the vertical cracks, which before had only been just visible, quite perceptible; at the same time giving a longitudinal crack across the key. These cracks, with the cracks in the ground, also shown in the diagram, show most undeniably that the cause of yielding was owing to the foundations slipping on the sandy soil in which the abutments had been built.

Such had been foreseen to a certain extent, and had been provided against by weighting the abutments, before the loading was commenced, by building up a square block over each 10′ × 10′, till it was equal to 30 tons. This weight prevented the overturning of the abutments, but was not sufficient to prevent the slipping. The load had been estimated by weighing 10 bricks, but, after the weighing was finished, a block of 100 cubic feet (5′ × 5′ × 4′) built of the bricks used in weighting was found to be 90 lbs. per foot, for the bricks were only sufficiently dry to handle.

As the cause of yielding was so palpable, it was no use adding more weight. Had the foundations stood firm, there is every reason to believe

that the great weight of half a ton nearly on every square foot would not have hurt the stability of the arch, since not one single crack was perceptible except those that must occur when foundations slip away from the thrust.

The whole weight was removed and a blast was fired in one of the abutments on the 24th August, that it might be tested whether the system of carrying up the works by layers, one inch or so thick, would not leave evidence that the mass consisted of a series of layers one inch thick. The result of the blasting shows that there is not a trace of how the work had been built. The effect of the charge is exactly similar to what it would have been had the charge been fired in solid rock. Only one piece, of about 2 cubic feet, was detached from the mass. It flew to a height of 20 feet and to a distance of 60 feet where it landed unbroken.

One interesting fact was brought to light by this blasting, viz., what is the state of mortar in a large mass of work six months after it has been built. The mortar consisting of one fat lime and one kunkur lime, is eminently hydraulic and will set completely in 36 hours. The results of the blasting showed, that although the mortar had set perfectly, the concrete was as wet as the day it was put in, and although it was as hard as stone, had a piece been put into water, I do not believe, it could have absorbed one drop. The outer six inches alone showed signs of dryness notwithstanding that the arch had been subjected to the enormous heat of an Indian summer.

Hence the necessity of using hydraulic lime in massive work, as an Indian sun is not sufficient to dry work that is five feet in from the face.

The experiment I think has proved that the system of consolidating concrete, composed of small materials and with little water in layers has been a success, but in future I would always recommend that brick should be substituted, for the one part of sand, as in a smaller arch made at the same time with the same lime, &c., but with brick substituted for the sand (making it three of brick instead of two), the work was undeniably stronger; moreover, as there would then be no sand, soorkee could be substituted for kunkur lime to render the fat lime hydraulic; thus if the Sirhind brick can be made use of, a further saving of fuel would be made.

# No. CCLXXXIII.

## THE SUTLEJ BRIDGE EXTENSION.

*Memo. on the extension of the Railway Bridge over the Sutlej, at Phillour.*
BY J. P. ANDERSON, ESQ., C.E.

EARLY in 1869 an estimate was submitted by me, and passed by the Punjab Government, for making an embanked roadway 5,300 feet in length over the sandy bed of the Sutlej river, from the left bank opposite Phillour, to a point abreast of the left abutment of the railway bridge. The embanked roadway was designed to save the yearly construction of a planked roadway over the sandy bed, and was to have been made on the down stream side of the bridge, so as to be protected by the railway embankment against floods. Shortly after this work had been commenced, I learnt that the railway authorities intended to extend their bridge by 2,000 feet, owing to the river having worked away from it.

As the proposed extension, if carried out, would have necessitated a reduction in the length of the sanctioned embanked roadway below the bridge, which would have been both inconvenient to traffic, and would have added to the expense of maintaining a good road over the sand, I drew out a memorandum on the subject, the substance of which is given below.

It is not, I think, contended by any one, that the original proposed length of the bridge, (viz., 4,200 feet,) is too small for the requirements of the river, but the reason assigned for extending the bridge, is that the river has receded towards the Loodianah side, and has left the railway bridge; I will, consequently, not here enter into the calculations for the waterway required, but will state first my objections to the proposed

extension, and will then show under the following headings how I propose the river should be dealt with :—

*1st.* By driving it under the bridge, as it is at present.

*2nd.* By making protective works to oblige the river in future to pass under the bridge and not endanger the railway embankment.

I annex for reference—*1st.* A memorandum on the Sutlej embankment at Ferozepore, which was made about 2½ miles in length from the left bank.

*2nd.* Plan showing the different streams in the Sutlej river, at Ferozepore, before the embankments were completed in 1862; also a plan showing the effects of the floods of 1862.

*3rd.* Plan showing the Sutlej river, at Ferozepore, with the embankments completed, and showing the river after the floods of 1863.

*4th.* Plan of the Sutlej river at Phillour, with railway bridge.

The objections to the extension are—*1st.* After the heavy expenditure of eight or nine lakhs has been incurred, nothing will have been done to confine the river within reasonable limits, and to fix its wanderings within the 6,200 feet given to it under the bridge. Last year, the river shifted 2,000 feet to the Loodianah side; this year it might go 2,000 or 4,000 feet further; if it does this, is the bridge to be extended another 4,000 feet? If the principle of following the river is adopted, we may have to bridge all the way into Loodianah.

*2nd.* By giving too large a waterway to the bridge, the river, not being able to use the entire length, will throw up silt in the part it does not use, and when the river sets in the direction of this silt, it will cut it away, and in so doing will scour its bed. Whereas, on the other hand, if only the full requirement of the bridge is given, and the river compelled to keep within this limit, once having formed its bed, it will keep to it without scouring to any great depth.

*3rd.* With the money scantioned for the extension, the river could be forced under the bridge, as it stands, and permanent protective works on the Loodianah side made for a length of two miles along the embankment.

The following is the mode in which I propose the river should be turned. Early in October the river should be surveyed and the point at which the river can be turned, fixed on; such a point can always be found within a mile of the bridge, it should have a shelving bank on the

Loodianah side, and the river would here have a set on to the Phillour side. At this point two channels, each 20 feet wide, 100 feet apart, and one foot below water surface should be cut, passing under the bridge and falling into any convenient nullah or into the river itself below the bridge.

From the Loodianah side, a spur should be run out above the mouths of the channels formed of *jhow* fascines, and sand or clay, but coated on the up-stream side with clay.

When the water becomes too deep to continue such a spur, country boats firmly anchored sides on to stream, and filled with sand and jhow, should be sunk and a bank formed between them.

When the river gets too deep for *this* to answer, floating boxes, each 50 feet long, 10 feet broad with perpendicular sides 12 feet high of 2-inch planking, ribs and floors, beams two feet apart, iron knees, and the interior strongly cross braced and filled with jhow and sand, should be placed sides on to the stream, and firmly anchored in a line from the end of the spur and sunk. If these boxes are sunk in the current of the river, they will, when sunk, cause the river to scour its bed in the line they sink, and to take a set in the line of scour; if this set throws the current on to the mouths of the new channels, they will be cut away to suit the requirements of the river. The essential points to the success of these floating boxes are—1st, That they be strongly made so as to not be broken to pieces by the force of the current; 2nd, That they should be firmly anchored so as not to be washed away in sinking; 3rd, That they should be sunk at such an angle to the current as will assist the river silting on to the mouths of the channel.

To keep the river permanently under the bridge, and to prevent its injuring the embankment, I propose that continuous masonry wells 4 feet interior diameter, with 1½ feet walling, should be sunk 50 feet deep, at the foot of the slope of the embankment on the up-stream side, and parallel with the line of railway for a length of 200 feet from the abutments on either side. The wells to be concreted, and masonry wing-walls raised on them. From the end of the wing-wall on the left bank, a masonry spur to be run out on wells similar to the above, sunk as close as possible to each other, and in a continuous line of 1,000 feet at right angles to the line of railway. Three of the end wells to be larger than the others, to have 15 feet interior diameter, 3 feet walling, and to be carried 60 feet, or as deep as it is possible to sink them; two small wells to be

sunk in the concavity between the large ones. The wells to be concreted, and masonry walls one and a half brick thick, raised 3 feet above highest flood level; seven more spurs 100 feet long to be made at right angles to the line of railway, and with intervals of 1,500 feet. The first 500 feet of these spurs to be of clay or sand coated with clay. Top of spur to be 8 feet wide, with slopes 1 in 15, and raised 6 feet above highest known flood, the remainder of the spurs to be of masonry $1\frac{1}{2}$ feet thick, walls on masonry wells 4 feet interior diameter. $1\frac{1}{2}$ feet walling with three large wells at end, as above.

This will give a permanent wing-wall on the right or Phillour bank, and as the right abutment is close up to that bank, which is high, and formed of hard kunkur soil, nothing further is required at present on that side. On the Loodianah side, permanent protective works will thus be given for a length of 10,750 feet or over two miles.

The cost of these wing-walls and spurs will be as per detail below:—

| | |
|---|---|
| 2 Wing walls, each 200 feet in length, at Rs. 27,500 each, | 55,000 |
| 1 Spur, 1,000 feet in length, all masonry, at Rs. 1,40,000 each, | 1,40,000 |
| 7 Spurs, each 1,000 feet in length, half masonry half sand and clay, at Rs. 80,000 each, ... ... ... ... | 5,60,000 |
| | 7,55,000 |

The extension of the bridge by 2,000 feet is to cost between 8 and 9 lakhs of rupees, without any works to confine the channel of the river, whereas by the above plan, for about the same sum, permanent protective works can be given for a length of 10,700 feet on the Loodianah side.

| No. | Description. | Cubic feet in each. | Total cubic feet | Rate. | Amount. | | | Total. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | RS. | A. | P. | RS. | A. | P. |
| 2 | Wing-walls, each 200 feet in length | | | | | | | | | |
| | Masonry, 54 wells, ... × | 1295·6 in each = | 69,962 = | 30 per 100 | 20,989 | 0 | 0 | | | |
| | Concrete ,, ... ,, | 628·3 ,, ,, | 33,928 ,, | 25 ,, | 8,482 | 0 | 0 | | | |
| | Well sinking, 54 wells ,, | 50 ,, ,, | 2,700 ,, | 8 ,, | 21,600 | 0 | 0 | | | |
| | Wall over well, 400 ,, | 3 × 10 ,, ,, | 12,000 ,, | 30 ,, | 3,600 | 0 | 0 | | | |
| | | Total cost of two wing walls, | | ... | ... | | ... | 54,671 | 0 | 0 |
| 1 | Spur, 1000 feet in length all masonry. | | | | | | | | | |
| | 124 wells, cost of each as above. ... ... | ... | ... | 946 per 100 | 1,17,304 | 0 | 0 | | | |
| | Masonry, 3 wells, ... × | 10,179 in each = | 30,587 | 30 ,, | 9,161 | 0 | 0 | | | |
| | Concrete ,, ... ,, | 10,602 ,, ,, | 31,806 | 25 ,, | 7,951 | 0 | 0 | | | |
| | Well sinking, 3 wells ,, | 60 ,, ,, | 180 | 12 ,, | 2,160 | 0 | 0 | | | |
| | Wall over wells, 1 ,, | 1000 × 15″ × 6′ | 7,500 | 30 ,, | 2,250 | 0 | 0 | | | |
| | | Total cost of one spur, | ... | ... | ... | | ... | 1,38,826 | 0 | 0 |

| No. | Description. | Cubic feet in each. | Total cubic feet | Rate | Amount. | | | Total. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Spur, 1000 feet in length, half clay half masonry. | | | | | | | | | |
| | 85 wells, cost of each, as above, ... .. | ... | ... | 946 | 54,868 | 0 | 0 | | | |
| | 3 large wells, as above, with wall, . | | | | 21,522 | 0 | 0 | | | |
| | Earth, 500 × | 98 × 6 = | 2,94,000 = | 10 per 100 | 2,940 | 0 | 0 | | | |
| | | Total cost of one spur, | ... | ... | ... ... | | | 79,330 | 0 | 0 |

*Memorandum on the embanked Roadway in the bed of the river Sutlej, at Ferozepore.*

*Jullunder, 14th June, 1869.*

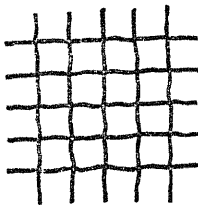
Previous to January 1862, the width of the river Sutlej, at Ferozepore, in a direct line from the metalled road on one bank, to the metalled road on the other bank, was a little over 5 miles. During the rains, there was not a piece of dry ground in the whole of these five miles. The main body of the water flowed sometimes through two, at other times through three or more channels, and between these channels there was marshy ground, through which the traffic of the country had to wade. Year by year the width of the river bed, and consequently the obstruction to traffic, increased, while, till 1862 no attempt had been made to keep the river within bounds. The river wandered uncontrolled over its bed of five miles, cutting away sometimes its right bank, at other times its left bank, and frequently finding its way through channels in different parts of its bed, but never at any time did it occupy the entire extent of five miles. The difficulties and annoyances in crossing were a great hindrance to traffic.

In January 1862, an estimate was sent in to raise an embanked roadway across the bed of the river, leaving a gap one mile in extent, about the centre of the bed, for the river to discharge itself through. The estimate provided for a road 30 feet at top, slopes 5 to 1, and raised $4\frac{1}{2}$ feet above highest flood level; the embankment was to have earthen spurs raised on a level with the road; they were to be placed 1,000 feet apart, at right angles to the embankment, and were to be 500 feet in length, the ends being protected with *bullies* and *jhow.*

For reference, *three* plans of the river are annexed: one shows the pro-

plosed embankments, and the river as it was before the embankment, from the Ferozepore side, was made; the second shows the two embankments made before the floods of 1862, and the effects of the river on the left bank during the floods of 1862; the third shows the embankment on the left bank completed, and the river bed after the floods of 1863.

Before the floods of 1862, embankment No. 1 had been run out 7730 feet in length to the edge of stream No. 2, and embankment No. 3 had been made 2,960 feet in length. A gap of 2,306 feet was left for stream No. 2, as will be seen from the plan. Both the embankments were completed, with their spurs 500 feet in length, and 1000 feet apart, and intermediate spurs 250 feet in length, which had subsequently been ordered.

In June 1862, the river commenced to rise, and took a set on to the left bank of stream No. 2. After each flood, it cut away a portion of the high land on its left bank, and endangered the safety of the embankment which had been formed on this land. To check this, rafts of bullies and jhow were anchored in the current, which had not the least effect on the action of the current: a number of bullies 12 feet long were then tied together, as per marginal sketch, and the interstices filled up with jhow

and clay, making a hurdle 10 feet long, 10 feet broad, and 5 feet high. It was placed at the edge of the bank which was being cut away, and was firmly secured with strong ropes. When the river cut away the ground on which the hurdle had been placed, it ell into the river and sunk. A deep hole was made in the river bed where the hurdle sunk, and in this hole the current turned. The left bank was cut away for about 200 more feet, after which the river stopped doing any further damage at this point, but went on cutting back towards Ferozepore. The main current kept on the spot where the hurdle had been sunk. Up to this time, the embankment for a length of about 930 feet had been carried away.

Finding the sinking of the hurdle so successful, another and a larger one was made at the end of spur No. 11. It was 10 feet broad, 70 feet long, and 10 feet high, and was firmly secured with strong ropes. After one of the floods in July 1862, the river cut away its left bank and carried away the ground on which the hurdle had been placed; the hurdle fell into the river head foremost, and caused a very deep hole to be formed on which the river again turned. There was only a depth of 8 feet of

water in the river all round the hole, but with two bamboos each 20 feet long tied together, I could not touch the bottom. The river continuing to cut back, a third hurdle was formed at spur 9, with similar success. Before anything could be done to protect spur No. 7, the river, in September, cut away its left bank still further, and carried away the ground on which the embankment was, between spurs 7 and 8, and made a gap in the embankments of about 400 feet. Two boats were sunk at spur 5, after which no further damage was done to the embankment.

While the river was cutting away its left bank, it threw up silt towards its right bank. In October, channel No. 2, down which the main body of water had flowed in the rains, settled up, when the damage done was repaired, and the embankments completed right across.

The silting up of channel No. 2 was due to the river having reduced the fall of its bed by one half, by its winding round by spur No. 4. The velocity having been decreased by the reduction of the fall, silt of course was deposited. Before the floods, the distance from A to B (plan No. 2) was under 5,000 feet, whereas in September the left bank from A to opposite B was about 10,000 feet.

I annex a Register of the highest flood lines taken along the new embankment. It will be observed that in 1862, along embankment No. 1, which was 7,730 feet long, the river rose $1\frac{1}{2}$ feet at the commencement, and $\frac{1}{2}$ a foot at its end above the highest known floods. In 1863, when the continuous line of embankment was 12,996 feet long, the river rose $3\frac{1}{2}$ feet at the commencement, and one foot at its end above the highest known floods before the embankment was made.

As stated above the slopes of the embankments and spurs were made at 5 of base to 1 of height; this was found to be too steep for the up-stream slope and for the spurs, as the splashing of the water washed the clay down to an inclination of from 10 to 1, to 15 to 1; the latter should I think be the slope, for all similar embankments on the up-stream side, and for all spurs.

The body of the embankment and spurs was made of sand, which was coated over with clay 2 feet deep on the down-stream side and on the roadway, and 3 feet deep on the up-stream side.

In the floods of 1863, the embankment had a narrow escape from being carried away; the flood waters rose nearly to the top of the embankment and a ridge was made at the up-stream edge of the road to prevent the pos-

sibility of the flood water over-flowing the embankments; the danger was due, in the first instance, to the action of wind and traffic for one year on the surface of the roadway bringing it below formation level, which would not have occurred had the road been metalled, and in the second to embankment No. 3 not having been completed to formation level.

It will, I think, be admitted, that the sinking of the hurdles and the boats turned the current of the river, and prevented its cutting away the whole of the ground on which the embankments stood; at each spur where a hurdle had been sunk, the river was turned and the embankment saved. The only point, where, owing to my absence from Ferozepore, nothing had been done, the river cut into the embankments, but, even then, the river went round by the points I had protected by the hurdles. From this, it might, I think, be accepted as a rule, that to turn the current of a river it is only necessary to throw into it a mass of either trees firmly held together, or of bullies and jhow, so strongly secured that the current does not carry it away.

The original project, as far as I am aware, has not been completed, the embankment from the Lahore side not having been made. As the embankment at the Ferozepore side has now stood for six years, and has greatly facilitated traffic across the river, it would be a blessing to the country if the embankment on the Lahore side were completed.

J. P. A.

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NOTE BY EDITOR.

I visited the site of the Railway crossing at Phillour in January, 1869, when the deep channel of the river had abandoned the bridge, and was then flowing between the left abutment and the Loodianah bank. The extension then proposed has since been actually made, and it remains to be seen whether the river will confine itself to its present channel or will work its way still more towards the Loodianah bank, and try to burst through the Railway embankment. If such an attempt be made and is defeated, it is difficult to understand why the river could not have been forced to flow under the bridge *before* the extra 20 spans were added (as there was no question of deficiency of waterway); at any rate it seems a great pity that the attempt was not made before the extension was determined on at the cost of several additional lakhs of rupees.

If the cold weather stream had been diverted in January 1869, (an

operation of no difficulty), and the railway bank had been completed up to the left abutment, and made double, with cross bunds between, (so as to isolate and silt up any breach in the outer bund,) I believe the attempt might have been successful. The most noticeable thing about the action of the river on the protective works was that while deep piles and even masonry wells were scoured out, spurs of brushwood which were simply *laid on* the bed of the river were unharmed. It looked as if any meddling with or disturbance of the bed was resented; while the water was willing to be guided so long as the bed was untouched; and I believe that an earthen bank with a long flat slope (10 or 15 to 1) will often be found to stand safely, while works driven at an immense cost into the bed will be scoured out and destroyed. On this principle, I believe, are river banks often adequately protected when the water has begun to scour them, by simply cutting them back to a long slope with perhaps turfing, brushwood or grass ropes added to protect the slopes.

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# No. CCLXXXIV.

## ARMY SIGNALLING AND TELEGRAPHY.

BY MAJOR W. HUDSON, *21st Punjab Infantry.*

THE subject of Army Signalling and Telegraphy is one which though it has occupied the attention of Military Authorities in most civilized countries for some years past, has but recently been brought prominently forward in England. The want of some system by means of which communication between the different parts of an Army in the field could be established and maintained, more especially in actual presence of an enemy, had made itself felt in almost every campaign of modern times. That this should have been so is scarcely to be wondered at, when it is considered how much the success of military operations depends on the means which a commander has at his disposal for ascertaining the intentions and movements of his adversary, and of communicating with celerity and precision his own orders for frustrating the dispositions of the hostile force.

The student of military history will have little difficulty in recalling numerous occasions on which the presence of a Field Telegraph Train, and a Corps of Signallers in the ranks of an army would have given a very different complexion to the results of a hard fought battle.

It is somewhat remarkable too, that this deficiency should have been so long allowed to exist in the British Army, when the Navy, with which, in the event of an invasion of England, that Army would be called on to co-operate, has brought its system of signalling to so much perfection.

The first occasion on which anything like an organized system of Tele-

graphy in connection with military operations was attempted in the British Army, was in the Crimean Campaign, when a Field Telegraph equipment was sent out with the Royal Engineer Train, and its wires laid from the head quarters of the Army, to Balaklava, to the head quarters of each Division, and to each of the attacks. By its means Lord Raglan was enabled to communicate with his Divisional Commanders at any hour of the day or night. It is also said to have been of great advantage in the trenches, as, in the event of any sortie by the enemy, reinforcements could be sent for, or instructions asked by the Commanding Officers on either attack.

The Field Telegraph was not, however, on that occasion, supplemented by any system of visual signals, and its operations were confined to fixed stations only.

The next occasion on which the Electric Telegraph was used by a British Army in the Field was during the Indian Mutiny Campaign of 1857-58, when that gallant officer, the late Lieut.-Colonel Patrick Stewart, of the Bengal Engineers, by whose death at Constantinople some years later, the country lost a most valuable servant, laid the Electric wires which kept Sir Colin Campbell in Oudh in close communication with the Governor General in Calcutta.

It was during this campaign, it is believed, that the first known attempt at Military Signalling was made. It was when the beseiged garrison of Lucknow, desiring to communicate with the garrison of the Alumbagh, (a post situated on the outskirts of the City,) established on the top of the highest building in the residency enclosure, a Semaphore Telegraph, constructed to work on precisely the same principle as that which before the introduction of the Electric Telegraph, was used by the Admiralty in London to transmit their orders to the fleet at Portsmouth.

By this means, communication was opened from the Residency *over* the rebel force in the city of Lucknow, to the Alumbagh, and thence to Sir Colin Campbell's retiring force.

It may here be remarked that had there been a Corps of Signallers present with the Army which, some months later, captured Lucknow, it would not have been necessary, in order that Sir James Outram on the left bank of the Goomtee might ascertain the movements of the troops operating on the right bank, to permit young Butler of the Bengal Fusiliers, to swim the river under fire of the enemy. A Corps of Signallers,

judiciously disposed, would have formed a link between the forces on either bank, and a few waves of a flag would have kept the two commanders constantly informed of the movements of their respective forces.

During the late Civil war in America, the greatest advantage was derived from the services of a Corps of Trained Signallers who, by means of flags by day and lights by night, supplemented the Field Telegraph, the wires of which it was often unadvisable or impracticable to lay beyond a certain distance.

Again, in the German War of 1866, the Prussians made great use of their Field Telegraph Train, though they do not at that time appear to have had any system of army signalling in connection with it, a deficiency which was much felt, as we learn from the talented author of the "Seven Weeks War," who says: "it is extremely improbable that a Prussian army will ever again take the field without a Signal Corps, such as those which were so successfully used by Federals and Confederates in the great American struggle."

More recently still, the system which we are about to describe, and which is the invention of Major F. Bolton, H. P. 12th Foot was tried in the Abyssinian Campaign of 1867-68. A Corps of Trained Signallers, selected from the detachment of Sappers sent out from England, was there employed under the immediate command of the late Lieut. Morgan, Royal Engineers. Their services are described by Lord Napier as having been "especially valuable in the advánce to Magdala in communicating with distant points relative to placing the guns in position." The success which attended this trial in Abyssinia appears to have confirmed the Military authorities in England in their determination to adopt Major Bolton's system, and to introduce it into the Army at home. A class of instruction was therefore established at the school of Military Engineering at Chatham, at first under Major Bolton's personal supervision, but he has since resigned his appointment, and has been succeeded by Captain Le Mesurier, R.E.

Here a proportion of Officers and Non-Commissioned Officers of each arm of the service in Great Britain are being gradually instructed, with a view to their becoming instructors to their respective corps. By this means, the system will ere long be disseminated throughout the home Army.

Useful, however, as the system must undoubtedly prove to the Army in England, it is to the Army of India that its introduction will be of

real practical advantage. It is in the "little wars" on our frontiers that it will be found invaluable.

How useful would not Chamberlain at Umbeyla have found a Corps of Trained Signallers. A few waves of a flag from the "Crag" picquet could have called for assistance at a critical moment, and might, in all probability, have saved that post from being more than once captured by the enemy; from whom, we cannot forget, it was only retaken, at a sacrifice of valuable lives, by reinforcements tardily called up by foot messengers from the distant camp.

We will now proceed to describe Major Bolton's system of signalling, and in doing so it will be convenient to adhere as closely as possible to the language used in the authorized "Manual of Instruction," published for the use of the classes at the school of Military Engineering at Chatham.

The system is known as the "Flashing system," and the mode of signalling adopted is by a combination of long and short "flashes," or "appearances" of any given object with proper intervals or obscurations between them, which are made by visual apparatus, such as revolving shutters or discs, collapsing cones, flags, bandroles, &c., by day; by lamps or lights by night; and by a combination of long and short sounds made by a fog-horn or bugle in fogs, or when visible symbols are not available.

Flashing signals are made by the motion of any single object.

In some instances the object is made to appear and disappear; and in others it is made to change its position, so that one position shall represent the appearance and the other the disappearance of the object.

The symbols are determined by successive appearances and disappearances at regulated intervals, constantly recurring after a fixed pause, in a manner precisely similar to those of revolving or flashing lights in lighthouses.

Signals made on this principle can therefore be scrutinized as long as may be necessary to make quite sure of their purport by comparison with the codes, before they are answered.

Every signal, consisting of from one to four numeral signs, with or without a special sign, is made to recur once in every 20 or 30 seconds; so that an observer watching a signal for three minutes may see it legibly repeated from six to nine times. This speed is found best suited to general service, and usually the observation of three repetitions is sufficient to make the signal understood without the possibility of mistake.

The appearances of the object are termed "flashes," and are of two lengths, termed respectively, "short" and "long flashes;" sometimes called "dots" and "dashes" which, separated by obscurations, are used in combination to express the signs required, and are usually written thus :—

■ .... To express the short flash or "dot."
▬ .... To express the long flash or "dash."

The interval of obscuration or the disappearance of the object being left blank.

At night, these signals are in all cases made by the obscuration and exposure of a single light; in the day time, by the different apparatus which may be employed. The system is equally applicable in fogs, long and short sounds on a bugle or fog-horn representing the long and short "flashes."

In all cases, the signals or combinations of long and short flashes, have the same signification, so that an observer, having learnt the nse of one apparatus, can read and make signals with every other description of apparatus without further instruction.

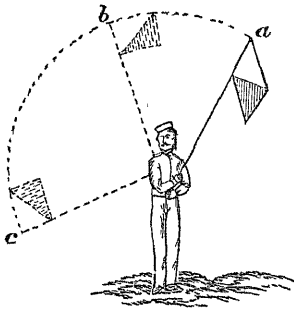
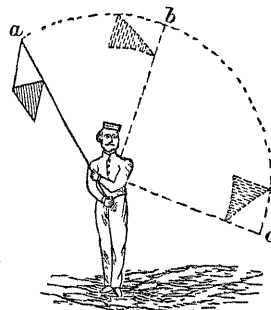
The following are the signs used :—

| | |
|---|---|
| 1 ■ | 6 ▬ |
| 2 ■ ■ | 7 ■ ▬ |
| 3 ■ ■ ■ | 8 ▬ ■ |
| 4 ■ ■ ■ ■ | 9 ■ ■ ▬ |
| 5 ■ ■ ■ ■ ■ | 0 ▬ ■ ■ |

There are also various auxiliary signs, such as—

"Compass"............ ▬ ■ ▬
"Numerical" ...... ▬ ■ ■ ■ ■
"Interrogative" ...... ■ ■ ■ ▬
"Negative"............ ▬ ■ ■ ■
"Alphabetical" ...... ■ ▬ ▬ ■

and some others. These auxiliary signs have the same signification, and are applied in the same way, as their corresponding symbols in "flag" signals. They are always to precede the figures forming the signal.

In "flashing signals" with flags, from the fact that flags are not fully exposed to view unless kept in motion, and as the plan of exposure and concealment cannot be employed in using them, a different arrangement is adopted.

The signal-man may work from left to right or from right to left as shown in *Figs.* 1 and 2, according to convenience or the direction of the wind.

To make a short flash, the flag is moved from *a* to *b* and back again to *a*. To make a long flash, the flag is moved from *a* to *c* and back again to *a*.

The numerals 1 to 5 are therefore denoted by one to five waves of the flag from *a* to *b*, recovering to *a*. The numeral 6, by a wave from *a* to *c*, recovering to *a*. The numeral 7, by a wave from *a* to *b*, back to *a*, and then to *c*, recovering to the normal position *a*; and so on with the others.

Each signal party consists of not less than two men, whose duties are as follows :—

In receiving messages.

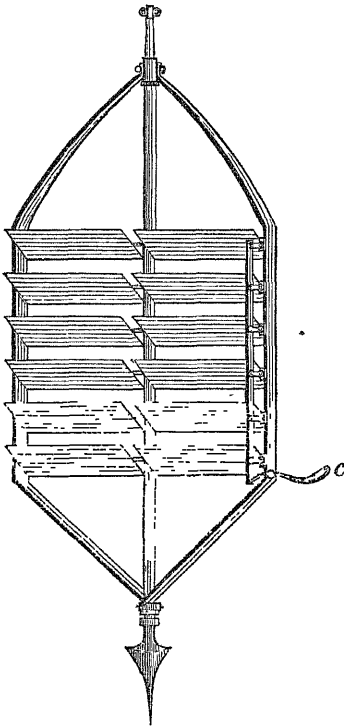
No. 1 works the flag for answering, &c., and refers to the code for the interpretation of the numbers received, and calls out the words to No. 2.

No. 2 fixes the telescope and reads from the distant station, calling out the numbers, as they are made, for the information of No. 1, and writes down the numbers and meaning thereof.

In all other respects, "flashing signals" are carried on in the same manner with flags as with any other instruments.

Another very useful apparatus for signalling between permanent stations

is the "revolving shutter," *vide Figs.* 3, 4 and 5. *Fig.* 3 exhibits the mechanism of the apparatus.

*Fig.* 3.

It may be made of any size corresponding to the distance required to transmit signals. An apparatus exposing a surface of 72 square feet will give a range of about 12 miles in clear weather.

It consists of a series of shutters each working on a pivot, and all connected together in such a manner as to move simultaneously by the motion of the handle *c*. When the shutters lie horizontal, as in *Fig.* 4, representing the obscured state of the light, an observer sees nothing, as at a short distance the skeleton frame is unseen, but when the shutters lie vertical as in *Fig.* 5, representing an exposure of the light, a very large surface comes into view. Signalling by this apparatus may be carried on with great rapidity, as the appearances and disappearances may be produced 100 times in a minute.

For short distances, "Hand-discs" may also be used, their range is about 2 miles. "Collapsing drums" are also used for signalling between shore stations and ships at sea.

For night signalling, the most effective apparatus is that known as "Bolton's Lime-light flashing apparatus," by means of which signalling may be carried on up to 25 miles. It is an adaptation of what is known as the "Drummond" light. The instrument consists of a combination of lenses for emitting parallel rays of light: behind the lenses, an improved safety jet is placed for burning, by means of a regulator, the hydrogen and oxygen gases.

The admixture of gases does not take place until in combination on

the pencil of lime, thus effectually preventing the possibility of an ex-

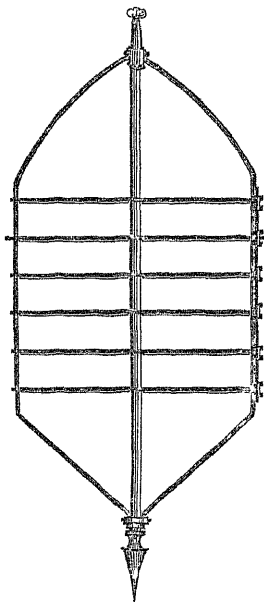
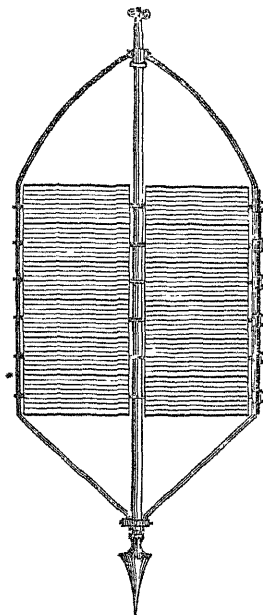



*Fig.* 4. *Fig.* 5.

plosion. The flashes are made by means of a mobile disc worked by a lever and finger key for shutting off and displaying the light.

In order to produce perfect combustion, the hydrogen and oxygen gases, being of two different densities, are brought into the open air at different angles; and a special contrivance in the manufacture of the burner secures an equal quantity of gas from each.

The apparatus contains generators and the requisite materials for making, as also bags for collecting the gases.

The oxygen mixture consists of

| | |
|---|---|
| Chlorate of potass, .. ... ... ... | 6 parts |
| Black oxide of manganese, ... ... ... | 1 „ |

1 lb. of this mixture produces sufficient gas to burn three hours, and it can be generated five times faster than the consumption.

The hydrogen mixture is

11 lbs. of zinc cuttings.
5 quarts of water, } previously
½ pint of sulphuric acid, } mixed.

A supply of which is maintained by the addition of sulphuric acid and water, 20 parts water to one of acid.

The light is obtained by first turning on a stream of hydrogen, which, when passing free from atmospheric air, will burn with a clear orange colored flame. This passes over the lime pencil and thoroughly heats it; the oxygen gas is then turned on and passes through and mixes with the hydrogen flame; thus united, the gases impinge on the point of lime and immediately render it incandescent.

The whole apparatus is very portable, two of them might be carried on a mule. The light is most brilliant, and signalling with this instrument is extremely simple.

Another instrument used for shorter distances is the "Chatham light." It consists of a simple oil lamp, on to the flame of which a jet of powder, called "Chatham powder," is, by means of an ingenious contrivance, flashed by bellows which are attached to the apparatus. The powder gives intense brilliancy to the light for longer or shorter periods, as may be required to produce long or short flashes. This "Chatham powder" consists of

| | | |
|---|---|---|
| Powdered magnesium, ... ... ... | 3 parts | (by weight) |
| Powdered resin, ... ... ... ... | 1 ,, | ,, |
| Lycopodium, ... ... ... ... | 1 ,, | ,, |

This lamp gives an excellent light, and is very handy; it has a range of from 5 to 10 miles, according to the strength of the powder, which depends on the quantity of magnesium used in the mixture.

For short distances, a mile or so, the ordinary hand-lamp with bull's eye is used; it is fitted with a metal shade on the inside, which is made to rise and fall by means of a key on the outside. In this way the operator can make long or short flashes at will.

The foregoing is a short description of the instruments and apparatus used in the new system of Army Signalling which has been adopted in the Home Army.

Enough, it is hoped, has been said to show the advantages of the system, which recommends itself chiefly on account of its simplicity, the ease with which a knowledge of it may be acquired by men of ordinary intelligence; and last, though by no means least in these days of Financial pressure, the inexpensive nature of the apparatus required for use. The whole of the instruments, if we except "Bolton's" and the "Chatham" lights, which would requir[illegible] be obtained, at all events in

the first instance, from England, could be constructed at the Roorkee Workshops. Such being the case, it is satisfactory to know that the subject has already claimed the attention of the new Commander-in-chief of the Army, and it is hoped that any recommendations which may be made to Government will not be confined merely to steps for the introduction of the new system of Signalling into the Army, but will also embrace the Establishment of a Field Telegraph Train, with mule equipment, so as to be ready to accompany any force which may henceforth be employed in Hill Warfare.

W. H.

# No. CCLXXXV.

## THE GANGES CANAL DURING THE FAMINE.

*Extracts from the Report of* LIEUT.-COLONEL H. A. BROWNLOW, R.E., *Superintending Engineer of the Ganges Canal, for the year* 1868-69.

*The Gross Revenue of the Ganges Canal* from all sources during the year amounts to Rs. 24,41,559. Of this sum Rs. 22,65,320 (92·78 per cent.) is derived from Water-rate, and the balance—Rs. 1,76,239 (7·22 per cent.) —from Miscellaneous Sources, including Rs. 88,910 (3·64 per cent.) credited under "Forests"—and Rs. 38,784 (1·59 per cent.) on account of Navigation Dues.

There has been an increase in total revenue over 1867-68 of Rs. 10,78,035, or 79·06 per cent.: in Water-rate of Rs. 10,26,830, or 82·91 per cent.: and in Miscellaneous Revenue (including "Forests") of Rs. 51,205, or 40·95 per cent.

*The Increase in Water-rate* is due—1st, To the excessive drought of the year under consideration; 2ndly, To an increase in the volume of water admitted into canal; and, 3rdly, To an improvement in the duty done, by the water. The khureef water-rate exceeded that of khureef 1867-68 (the highest up to that time) by Rs. 2,51,705, or 44·71 per cent.; while the rubbee revenue exceeded that of rubbee 1866-67 (the highest known before) by Rs. 5,57,029, or 62·33 per cent. From the beginning of August to the end of January, there was a constant and eager demand for water, which required the most vigorous exertions on the part of all canal officials to satisfy it.

The appended *Statement of Rain-fall* at the principal stations along the Ganges Canal during each month of 1868-69, shows how great was the drought in the several districts watered by the canal from the beginning of August 1868 to end of January 1869 :—

| Month. | Roorkee. | Moozuffernuggur. | Meerut. | Boolundshuhur. | Allygurh. | Mynpoorie. | Etawah. | Cawnpore. |
|---|---|---|---|---|---|---|---|---|
| | inches. | inches. | inches. | inches | inches. | inches. | inches. | inches. |
| April, 1868, ... | 0·1 | 0·1 | 1·0 | 1·4 | 0·2 | 0·4 | ... | ... |
| May, " ... | 1·3 | 0·1 | 0·9 | 1·0 | 1·8 | 1·1 | 1·3 | 0·6 |
| June, " ... | 4·8 | 1·4 | 1·0 | 1·5 | 0·7 | 0·4 | 0·6 | 1·5 |
| July, " ... | 8·9 | 9·1 | 9·7 | 6·6 | 4·6 | 6·1 | 6·7 | 2·7 |
| August, " ... | 2·0 | 1·0 | ... | 0·2 | 0·3 | 1·2 | 0·6 | 1·0 |
| September, " ... | 0·8 | 0·4 | 0·4 | 1·2 | 0·5 | 2·7 | 6·3 | 4·6 |
| October, " ... | ... | ... | ... | ... | ... | ... | ... | ... |
| November, " ... | ... | ... | ... | ... | ... | ... | ... | ... |
| December, " ... | 0·1 | ... | ... | ... | ... | ... | 0·4 | ... |
| January, 1869, ... | 2·2 | 2·2 | 0·9 | 1·1 | 1·2 | 1·1 | 0·7 | ... |
| February, " ... | 1·0 | 1·5 | 0·5 | 0·4 | 0·2 | ... | ... | ... |
| March, " ... | 2·0 | 2·8 | 2·4 | 1·2 | 1·3 | 0·1 | 1·5 | 1·1 |
| Totals, 1868-69, ... | 23·2 | 18 6 | 16·8 | 14·6 | 10·8 | 13·1 | 18·1 | 11·5 |
| Totals, 1867-68, ... | 59·5 | 39·2 | 36·6 | 39·1 | 29·5 | 56·6 | 53·1 | 52·3 |
| Decrease in fall of rain during 1868-69, ... | 36·3 | 20·6 | 19·9 | 24·5 | 18·7 | 43 5 | 35·0 | 40·8 |

*The Calculation of Discharges* on the Ganges Canal is attended with not a few difficulties at present. When a high supply is admitted into the canal, the bed begins to scour out; and as more and more water is passed down from the head to keep up the gauges below, a very considerable increase in sectional area of channel is gradually effected by the action of the water alone. On the other hand, when a low supply is flowing in the channel, silt is deposited with greater or less rapidity; and, after three or

four months of a *low* supply, the sectional area of channel corresponding to any given height of a canal gauge may be very much less than the area corresponding to the same gauge reading after three or four months of a *high* supply. Any theoretical deduction of discharges for various heights of a gauge, from one or two measurements of dischargecorresponding to given heights on that gauge, becomes under such circumstances inaccurate. The only way, then, to arrive at correct results is to be always measuring discharges, and this it is impossible for the few officers capable of performing the operation correctly to do during a year of drought.

I am sure, from measurements taken by myself and Lieutenant Corbett at Toghulpore, in the month of August 1868, and subsequently checked by Lieutenant Corbett in October, that fully 6,000 cubic feet per second, if not more, were passing the Roorkee bridge during October 1868. But a calculation of the average discharge for that month, based on measurements made during March and April, 1869, would give about 5,600 cubic feet as the utmost allowable figure. I have taken the larger volume as correct for the months of August to December inclusive. The estimate of loss by absorption (20 per cent.) may be considered somewhat low for a year of drought, but it is better to under-estimate than to over-estimate this; and the long-continued high supply in the canal must, after some time, have checked, in a great measure, the drain upon itself by fully saturating the adjacent ground. In fact, the greater ease with which gauges were kept up during October and November, as compared with August and September, was a matter of common remark at the time.

Some remarks seem advisable on the *Volume available for the Irrigation of the Rubbee crop*, with reference to the much-disputed question of proper capacity to be given to irrigation canals in these Provinces. The rubbee "puleo" was, as I have mentioned in the previous paragraph, started with a magnificent supply of at least 6,000 cubic feet per second during October, and the volume in the canal fell to an average of 4,200 cubic feet per second in January. The decrease, 30 per cent., is a mere trifle to that considered allowable by the advocates of a capacity to be limited only by the volume available at sowing time. And yet I have no hesitation in saying that, but for the timely and providential fall of rain in the end of January, there would have been failure of crops, and consequent bitter discontent over considerable areas in the districts below Meerut. I well remember the anxiety I felt on this point during January, and the evident

impossibility of our supplying at once the wide-spread demand for water at that time. The cultivators, too, as far as I could ascertain, were not at all prepared to accept remission of water-rate as an acquittance in full of all claims on the canal. Not a few openly told me, when I promised full remission in case of loss of crop, that they had sowed on the faith of obtaining canal water, and looked to the canal to mature their crop. In fact, the very objections to an early watering, largely in excess of any, subsequently possible, which are so strongly urged by His Honor the Lieutenant-Governor, North Western Provinces, in the papers lately circulated on this subject, were most strongly felt by these men. The results of the season may, perhaps, be quoted on both sides of the question; as there can be no doubt that, thanks to the high supply at sowing time and to the timely rain in January, a very much larger area of spring crops was brought to maturity than would otherwise have been possible; and I do not mean in any way to advocate a strict limitation of rubbee waterings at sowing time to the minimum volume likely to be subsequently available; but I do think that we should most carefully avoid risking the credit of 'Government by any speculative proceedings, and that if we wish, in this part of India, honorably to fulfill the just expectations of the irrigating community, we must never lose sight of the minimum volume of the river in designing channels intended for the irrigation of the rubbee crop.

*The Area Irrigated* during 1868-69 was 1,078,399 acres, more than double that of 1867-68 which only amounted to 533,456 acres; and 69·9 per cent. in excess of that for 1866-67. the highest previously obtained. Of the total increase over 1867-68, amounting to 544,942·99 acres, 159,130·22 acres occurred in the khureef (including sugar-cane). Sugar-cane increased from 55,232 acres in 1867-68, to 60,664 acres during 1868-69; cotton from 5,616 to 44,213, an area nearly 8 times that of the previous year; Indian-corn from 1,754 to 31,209, about 18 times the previous area; rice from 36,365 to 43,355; while there was a slight falling off in indigo of 178 acres. The increase of the rubbee area of 1868-69 over that of 1866-67 (including sugar-cane in both cases), was 299,702 acres, or 60·5 per cent. Barley increased from 121,126 acres irrigated during 1866-67 to 242,354, or 100·01 per cent. during 1868-69; gram from 28,397 to 39,985, or 40·80 per cent.; and wheat from 279,318 during 1866-67 to 418,228, or 49·37 per cent. during 1868-69.

A comparative *Abstract of Annual, Khureef and Rubbee Irrigation* during 1868-69 and 1867-68, is given below.

| Season. | Crop. | 1868-69. | | 1867-68. | |
|---|---|---|---|---|---|
| | | Acres. | Per cent. | Acres. | Per cent. |
| Annual, .. | Sugar-cane, .. .. .. | 60,664 | 5·63 | 55,232 | 10·36 |
| Khureef, ... | Cotton, .. .. .. .. | 44,213 | 4·10 | 5,617 | 1·05 |
| | Indian-corn, .. .. .. | 31,209 | 2·89 | 1,754 | 0·33 |
| | Indigo, .. .. .. .. | 75,506 | 7·00 | 75,684 | 14·18 |
| | Rice, .. .. .. .. | 43,355 | 4·02 | 36,365 | 6·82 |
| | Miscellaneous khureef irrigation, | 89,321 | 8·28 | 10,486 | 1·97 |
| | Total, .. .. | 293,604 | 26·29 | 129,906 | 24·35 |
| Rubbee, ... | Barley, .. .. .. .. | 242,354 | 22·47 | 88,156 | 16·52 |
| | Gram, .. .. .. .. | 39,985 | 3·71 | 13,274 | 2·49 |
| | Wheat, .. .. .. .. | 418,228 | 38·78 | 231,559 | 43 41 |
| | Miscellaneous rubbee irrigation, | 33,565 | 3·12 | 15,329 | 2·87 |
| | Total, .. .. | 734,132 | 68·08 | 348,318 | 65·29 |
| Totals, ... | Annual, .. .. .. .. | 60,664 | 5·63 | 55,232 | 10·36 |
| | Khureef, .. .. .. .. | 283,604 | 26·29 | 129,906 | 24·35 |
| | Rubbee, .. .. .. .. | 734,132 | 68 08 | 348,319 | 65·29 |
| | Year, .. .. | 1,078,400 | 100·00 | 533,457 | 100·00 |

*The Proportion of areas of Annual, Khureef and Rubbee Irrigation,* for the last four years, are—

| | *Annual.* (*Sugar-cane.*) | *Khureef.* | *Rubbee.* |
|---|---|---|---|
| 1865-66, | ... 10 | 21 | 69 |
| 1866-67, | ... 7 | 22 | 71 |
| 1867-68, | ... 10 | 25 | 65 |
| 1868-69, | ... 6 | 26 | 68 |

*The Proportions of "Flow" to "Lift" Irrigation* are as follow :—

| | Annual. | | Khureef. | | Rubbee | | Total. | | Grand Total. |
|---|---|---|---|---|---|---|---|---|---|
| | Flow. | Lift. | Flow. | Lift. | Flow. | Lift. | Flow. | Lift. | |
| Acres. | 43,887 | 16,777 | 193,394 | 90,210 | 474,293 | 259,838 | 711,574 | 366,825 | 1,078,399 |

The following abstract shows *Per-centage of Irrigation in each class* for the last five years :—

| Year. | Class I. | Class II. | Class III. | Class IV. | Totals. |
|---|---|---|---|---|---|
| 1864-65, ... ... ... | 9·20 | 5·05 | 84·08 | 1·67 | 100·00 |
| 1865-66, ... ... ... | 10·50 | 5 35 | 78·15 | 6 00 | 100 00 |
| 1866-67, ... ... .. | 7·30 | 6·57 | 83·35 | 2 78 | 100 00 |
| 1867-68, .. ... ... | 10·36 | 8·94 | 78 29 | 2 41 | 100·00 |
| 1868-69, ... ... ... | 5·63 | 5·45 | 77·71 | 11 21 | 100 00 |
| Mean, ... | 8·60 | 6 27 | 80 32 | 4·81 | 100 00 |

Deducting from the mean discharges at Roorkee the mean volumes passing out of canal through the terminal escapes, *the Area irrigated per Cubic Foot per second* was, for the khureef, $\left(\frac{344,268}{4,623}=\right)$ 74·47 acres ; for the rubbee, $\left(\frac{794,794}{4,668}=\right)$ 170·26 acres, and for the year, $\left(\frac{1,078,399}{4,646}=\right)$ 232·11 acres ; sugar-cane irrigation being included in both khurreef and rubbee areas. During 1867-68, the duty for the khureef was 47·23, for rubbee 131·0 acres, and for the whole year, 152·4 acres.

*The Water-rate derived from each Cubic Foot per second* of mean available supply was, for the khureef $\left(\frac{814,631}{4,623}=\right)$ Rs. 176·21 ; for the rubbee $\left(\frac{1,450,689}{4,668}=\right)$ Rs. 310·77 ; and for the year $\left(\frac{2,235,320}{4,646}=\right)$ Rs. 487·58 ; water-rate on sugar-cane being included in annual and khureef assessments only. During 1867-68 the water-rate per cubic foot per second amounted to Rs. 143·6 for the khureef, Rs. 219·3 for the rubbee, and Rs. 353·8 for the year.

*The Water-rate per Acre Irrigated* is compared below with that of the three previous years :—

| | | *Khureef.* | *Rubbee.* | *Year.* |
|---|---|---|---|---|
| 1865-66, ... | ... | 2 82 | 1·99 | 2·22 |
| 1866-67, ... | ... | 2·76 | 1·99 | 2·22 |
| 1867-68, ... | ... | 3·00 | 1·95 | 2·32 |
| 1868-69, ... | .. | 2·37 | 1·98 | 2·10 |

The decrease observable in rate per acre irrigated during 1868-69 is caused by the largely increased proportion of 4th class crops watered during the year. This cause did not decrease the value of water-rate derived from each cubic foot of water delivered, as the duty done by the water increased considerably during the year.

*The Number of Villages taking water* was 4,634 during the khureef, and 5,795 during the rubbee crop of 1868-69. During 1867-68, the number was 3,994 during the khureef, and 4,520 during the rubbee crop :—

*The Cost of Maintenance* during the year amounted to Rs. 757,313, as follows :—

| Year. | Division | Repairs. | Plantations | Establishment | Total. |
|---|---|---|---|---|---|
| 1868-69. | Total, .. | 321,547 | 31,600 | 404,166 | 757,313 |
| | Percentages, | 42 46 | 4·17 | 53 37 | 100·00 |

The total cost of maintenance during 1868-69 amounted to $\left(\frac{7,57,313}{654}=\right)$ Rs. 1,158 per mile of main canal; $\left(\frac{7,57,313}{4,952}=\right)$ Rs. 152·9 per cubic foot per second of average discharge passing Roorkee, and $\left(\frac{7,57,313}{10,78,399}=\right)$ Rs. 0·70 per acre irrigated. The cost of rajbuha repairs, and silt clearance amounted to $\left(\frac{1,59,121}{3,112}=\right)$ Rs. 51·13 per mile of rajbuha channel; in 1867-68 it amounted to Rs. 54·8 per mile, and in 1866-67 to Rs. 68·5 per mile. During 1866-67, the total cost of repairs to the canal and its rajbuhas amounted to Rs. 3,82,622 ; and it will be seen that there has been a steady decrease in the expenditure under this head during the two succeeding years, although the cost of establishment has undoubtedly increased. Part of this increase is due to the expansion of irrigation, and part to the additional charges incurred on establishments employed in drawing up projects for improvement of the canal, and for supplementing its volume.

The high cost of repairs on the main channel of the Ganges Canal, as compared with the Eastern Jumna Canal and others, is to a certain, and by no means inconsiderable, degree attributable to its magnitude and great length. For the first 180 miles at least from its head, it is no gentle stream to be diverted from and restored to its course as occasion may require, but a swift and deep river, exerting most formidable powers of destruction at each of the numerous masonry falls along its course. Also the numerous interests involved, and the various natures and conditions of growth of the staple crops dependent upon it, render a closure which

admits of the execution of proper repairs, a matter of comparatively rare occurrence. Work has to be executed hurriedly (work against time being notoriously expensive), and the water has often to be turned on to green masonry, because a pressing demand has arisen in some part of the canal. The warning contained in the old proverb about the "stitch in time" must be in a great measure disregarded in canal maintenance. The Superintending and Executive Engineers may know full well of a hole in a fall flooring, which could be repaired at comparatively trifling cost, could they only get at it. But a closure at the time would create an uproar of discontent, not to say a perfect panic, amongst the cultivators of half a dozen districts; so the best that can be done under the circumstances is done. The temporary repair costs money, and the permanent one has still to be carried out, at perhaps tenfold cost, when an opportunity for it may offer itself. The Ganges Canal has also to bear the outlay on works and establishment required for navigation, facilities for which are not provided on any other canal in the North Western Provinces; and if, as I believe is the case, the general charges for direction, &c., are distributed in proportion to the expenditure incurred on each canal, this arrangement must further enhance our already heavy outlay. The expenditure on rajbuhas has decreased steadily of late years; and, considering the comparative newness of their banks, it will, I think, stand, a comparsion with that on the Eastern Jumna, or any other canal.

*The Amount of Compensation paid* for damage done by breaches in rajbuha banks and by intercepted drainage during 1868-69, was Rs. 7,738.

*The Remissions of Revenue* amounted to Rs. 1,989-9-1. During the previous year they amounted to Rs. 4,928-5-10, during 1866-67 to Rs. 5,615-2-1, and during 1865-66, to Rs. 6,784-7-10.

The following Statement shows *the Balances of Water-rate and of Miscellaneous Revenue Outstanding* on 31st March, 1869:—

| WATER-RATE. | | | | MISCELLANEOUS REVENUE. | | |
|---|---|---|---|---|---|---|
| Year. | RS. | A. | P. | RS. | A | P |
| 1868-69, .. .. | 1,18,055 | 7 | 8 | 6,799 | 7 | 8 |

Appended is a Statement of *the Cost of Realizing the Water-rate*:—

| Year. | Collections | Payments. | | | | Percentage of payments on collections, 1868-69. | Percentage of payments on collections, 1867-68 |
|---|---|---|---|---|---|---|---|
| | | Lumberdars' fees | Establishment. | Contingencies, including Stationery. | Total. | | |
| | RS. A. P. | RS. A. P. | RS. A. P. | RS. A. P. | RS. A. P. | | |
| 1868-69, | 14.54,652 15 8 | 17,337 3 0 | 6,666 2 2 | 1,837 0 1 | 25,840 5 3 | 1·776 | ... |
| 1867-68, | 14,90,767 7 10 | 17,386 8 11 | 6,389 0 8 | 384 11 0 | 24,160 4 7 | ... | 1·620 |

*The Fines levied* during the year amounted to Rs. 13,984, including Rs. 7,476, for wastage of water. They average per village irrigating from canal during the khureef of 1868-69, Re. 1·02; per village irrigating during the rubbee, Re. 1·63; and Re. 1·34 during the year.

The following Statement shows *the Income derived from, and Expenditure incurred under, "Forests"* on the Ganges Canal, during 1868-69, as compared with 1867-68 :—

| Year. | Income. | | | Expenditure. | | | |
|---|---|---|---|---|---|---|---|
| | | | | Maintenance of | | | |
| | Firewood and Charcoal | Fruit, seed, grass, &c. | Total | Mango Gardens. | Canal bank Plantations | Establishment. | Total. |
| | RS. A. P. | RS. A. P. | RS. A. P. | RS. A. P. | RS. A. P | RS. A. P. | RS. A. P. |
| 1868-69, | 69,505 2 5 | 22,002 9 7 | 91,507 12 0 | 1,862 3 5 | 25,118 2 8 | 4,620 9 8 | 31,600 15 9 |

There has been a large increase in receipts and a slight decrease in expenditure; but there is no special cause for congratulation on this account, as it is very much easier to sell trees than to grow them, and we have reaped during the year under review the fruits of other's labors. Large sales were effected in the Meerut division of canal on decidedly advantageous terms to the Delhi Railway and Meerut Division of Public Works Department. Sales to a smaller extent were made in the Allygurh and Etawah division to "stock" for the burning of bricks; most vigorous and well-directed efforts will be required to replace the felled timber and to hand over to our successors the plantations in the same thriving condition as that in which we received them. I hope that the future allotments

for expenditure on plantations of Ganges Canal may not be cut down with regard to previous short expenditure during seasons of drought, but that every encouragement may be afforded by Government to well-considered outlay on their improvement.

*The Gross Revenue realized in the Navigation Department* was—

| | | | | | | |
|---|---|---|---|---|---|---|
| For the half-year ending 31st September, 1868, .. .. | | | | Rs. 20,429 | 6 | 4 |
| For the half-year ending 31st March, 1869, .. .. .. | | | | „ 18,354 | 6 | 1 |
| Total gross revenue, 1868-69, .. | | | | „ 38,783 | 12 | 5 |
| being 10·3 per cent. more than that of 1867-68. | | | | | | |
| The cost of establishment was, .. .. | Rs. 9,581 | 12 | 5 | | | |
| Refunded to boat proprietors on account of closure of canal, .. .. .. .. | „ 3,299 | 7 | 10 | | | |
| | | | | 12,881 | 4 | 3 |
| Leaving a net revenue of .. .. | | | | Rs. 25,902 | 8 | 2 |

The following are the sources from which the total gross revenue was realized, viz :—

| | | | |
|---|---|---|---|
| From Boats, .. .. .. | Rs. 22,224 | 1 | 10 |
| „ Rafting, .. .. .. | „ 14,806 | 10 | 5 |
| „ Miscellaneous profits, .. | „ 1,735 | 0 | 2 |
| Total Rupees, .. | 38,783 | 12 | 5 |

Of the gross increase in revenue during 1868 69 over that for 1867-68, amounting to Rs. 3,566, Rs. 791 were derived from boats; Rs. 1,776 from rafts; and Rs. 999 from miscellaneous sources. The average number of boats plying on canal increased from 450 during 1867-68 to 487 during 1868-69. The drought gave a great impetus to the grain traffic; while that in cotton, oil seeds, and salt, fell off. There was also a large increase in amount of building materials boated down canal. Under the head of rafting, there was a large increase in number of bamboos, bullies, and kurries, and a falling off in firewood and tors. Passengers decreased in number owing to the smallness of the Hurdwar fair of 1868.

All officers connected with the canal worked most nobly through the drought. I think it would be hard to find a body of men who devoted themselves more unanimously and unsparingly to their duty throughout the whole of the trying year under consideration.

H. A. B.

# No. CCLXXXVI.

## SAINT ANDREW'S CHURCH—KURRACHEE.

The above named Church stands in a walled enclosure of about two acres in area. It was designed by T. G. Newnham, Esq., C.E., Chief Resident Engineer of the Sind Railway, and in style is Gothic of the 14th century. The work was commenced in 1867-68, and the Church was opened for divine service on the last day of the latter year. The building was erected by contract by Messrs. McKenzie and Bosser. The entire cost was Rs 56,000, of which sum Rs. 25,000 were contributed by Government.

This Church is sufficiently large to seat 400 persons. It consists of a nave 100 feet by 40 feet, which runs North and South, and is divided by arcades of horse-shoe arches supported on clustered pillars, from the side aisles, which are 8 feet in width. On each side of the nave and above the arcades are ten clerestory windows. There is a fine rose window, 18 feet in diameter, at the South end of the nave, and at the Northern end there is a fine light window with a head of Geometrical tracery. The outer walls of the aisles are pierced with windows with segmental heads, and the walls are strengthened exteriorly by flying buttresses. The corrugated iron roof is supported on angle iron trusses, and the ceiling is of deodar planking supported on teak wood ribs, which are attached to the tie-rods; the ceiling of the aisles is of plain deodar and planking. At the South Western corner of the building, there is an Octagonal Porch, 12 feet 9 inches in diameter, with a conical roof of corrugated iron; and at the South Eastern corner there is a tower and stone spire rising to a height of 125 feet. The masonry is of stone and lime throughout, and, with the exception of the ceiling, the wood-work is entirely of teak.

P. P.

# No. CCLXXXVII.

## RESTORATION OF THE MHOW-KE-MULLEE VIADUCT.

By Alexander Robert Terry, *Assoc. Inst. C.E.*

(From the Proceedings of the Institution of Civil Engineers)

The new Mhow-ke-Mullee, or No. 5, viaduct, is one of the largest works on the Bhore Ghât pass of the south-eastern branch of the Great Indian Peninsula railway, which branch, when completed, will, with the Madras railway, connect the Presidency towns of Bombay and Madras.

The old viaduct was 168 yards long, and the level of the rails was 163 feet above the lowest foundation. It was constructed of masonry, and consisted of two abutments and seven piers, with eight semicircular arches, each of 50 feet span. It was built of block-in-course face-work, with the internal work of rubble. The line approached the viaduct at a gradient of 1 in 40, on an embankment 100 yards long, and 70 feet in height at the abutments. It passed the viaduct at the same gradient, and with a curve of about 30 chains radius, and entered a tunnel about 50 yards from the end of the masonry.

Early in 1867, this viaduct, which had then been opened about four years, was reported to have shown signs of weakness in one of the lofty piers; and five months afterwards it gave way entirely, during a violent storm of wind and rain, the actual destruction being so rapid that in less than twenty minutes after the first observed movement, not one arch or pier remained, the abutments alone standing. This happened on the 19th of July, 1867, a few minutes before two trains were due at the viaduct. The ascending train was, in fact, within about 100 yards, so

that the driver witnessed part of the fall; the other was late, and was fortunately stopped before it had entered the tunnel next the viaduct. In order to carry on the traffic, which amounted to about eighteen trains per day, during the reconstruction of the viaduct, a line of rails was laid, following the contour of the Mhow-ke-Mullee ravine, in such a manner that the trucks, descending freely on one side, could work up the greater part of the other side by the momentum acquired, when they were drawn up to the top by engine-power (*Plate* XXIX). This temporary line commenced 700 feet from the north-west abutment, and descended to the centre of the ravine by gradients of 1 in 20 and of 1 in 7½. The length of this line, from the starting-point to the bottom, was about 1,000 feet, and the depth descended about 56 feet. The ascent on the other side had similar gradients, with curves of 20 chains and of 10 chains radii, until a point about 1,400 feet from the commencement of the incline was reached, where a crossing was introduced, and the gradients adopted were 1 in 37 and 1 in 5¾ for a distance of 360 feet beyond the points where this branch of the incline terminated. From the same crossing a line was constructed in the opposite direction, with a curve of 5¼ chains radius, and a gradient of 1 in 8¾, for a length of about 400 feet, and then straight and level for a distance of 210 feet, to turn-tables at the end of the main line tunnel. The total length of the temporary line was 2,370 feet.

Owing to the difficulties of the ground, and the interruptions caused by the weather, this work was not completed till October, when the goods traffic, which, for above three months, had been worked by the company over the turnpike road of the Ghât Pass, was conveyed across on this line, and was successfully carried by it for upwards of eight months, at the average daily rate of two hundred and fifty wagons. The working was as follows: the trains which ascended the Ghâts were divided into lots of two wagons each, and were then pushed over in pairs from the main line on to the tramway by a locomotive, at velocities of from 10 miles to 15 miles per hour, which increased to about 40 miles by the time the bottom of the incline was reached. The wagons then ascended on the other side of the gap, a height of about 46 feet, where they passed the points. Their motion was then reversed, and they traversed in the direction of the tunnel at the south-east end of the viaduct. A 5-inch wire rope was then hooked on to them, and attached to a powerful engine working on the main line, which drew them up to the top, where they

formed into a train. The wire rope, about 150 yards long, passed from the engine over a pulley, 8 feet in diameter, under the main line (which was at a sharp angle with that part of the tramway), and was guided from thence by several smaller pulleys and rollers between the rails. The wagons descending the incline were also lowered in pairs to within a few yards of the crossing by means of the same rope and engine, when they ran by gravity past the points and up the incline beyond them. From thence they descended to the bottom of the ravine, and ascended the other side to the top of the gradient of 1 in $7\frac{1}{2}$. A goods engine was then backed down on the gradient of 1 in 20, and drew them up.

The structure to replace the original viaduct consisted of abutments 28 feet in advance of the old abutments, connected thereto by side-walls, and of one solid ashlar pier in the centre of the viaduct, on which iron girders of 202 feet clear span rested. These girders were expected to arrive at an early date in Bombay, for the purposes of another viaduct on an unopened part of the line. The gradient was altered from 1 in 40 to 1 in 60, and the line taken straight, instead of on a curve, across the new viaduct.

The contract for the masonry was let to Messrs. Glover and Co. early in September, 1867, on condition that their work should be completed by the end of March, 1868, which it was calculated would afford sufficient time for the Company to erect the iron girders before the monsoon.

The contractors immediately commenced operations, by opening extensive quarries near the works, and by excavating the pits for the foundations. The ground where the pier was to be built was covered with blocks of masonry, and a mass of loose, crumbling material, which made it necessary to enlarge the mouth of the pit much beyond the actual requirements; and it was found, on reaching the rock, that the latter dipped so rapidly, that a large mass had to be blown away before level surfaces, of sufficient size of the abutments and the pier, could be obtained. The depth of the pier foundation was 48 feet below the surface of the débris; the first course of masonry in the pier could not consequently be laid before January, 1868. The abutments had been founded in the previous month. After this, a large quantity of stone having been prepared, the work progressed rapidly, from 70 tons to 80 tons of stone being daily hoisted up and built into the pier. Excepting a void, 19 feet by 4 feet, in the middle, the masonry of the pier consisted entirely of solid block-in-course. The courses were laid alternately header and

stretcher, and were so built that the header in one course was, as nearly as possible, over the centre of the space between those in the course below it. The filling-in consisted of two courses to one of the face and through stones, and was mostly made up from the material of the old viaduct. The five upper courses and that immediately below the bed-girders, which was 2 feet 3 inches thick, were set in cement, and the stones of this last course were so disposed, that the weight of the girders should be distributed by means of the bed-girders over the whole area of the masonry. The courses were 15 inches deep, and generally the blocks were 18 inches wide and 3 feet 6 inches long. The pier was finished on the 15th of May, or five months after the first course was laid, its height being 165 feet.

The abutments were of block-in-course facing, with sound flat-bedded rubble backing, well bonded with throughs; five courses under the girder bed blocks were also carried up in solid ashlar blocking, set in cement. The abutments had progressed at about the same rate as the pier, and were delivered over to the Company, for the erection of the girders, about two months after the contract time.

While the masonry was in progress, a staging, upon which to erect the girders, had been carried across the ravine, its height above the débris at the middle being about 63 feet. There were two platforms, the one 18 feet below the other, both 36 feet wide, and both supported by heavy timbers, bearing on thirteen piers 33 feet 6 inches apart. Of these, the ten intermediate ones were each of three columns in a row, but those at the ends and in the middle were clusters of five and six, the whole well braced together. The columns, all 30 inches in diameter, were of cast-iron, in lengths of 9 feet, bolted together, each length weighing 30 cwt. The thickness of the metal was 1⅛ inch. The columns had internal flanges at the ends for the bolts and lugs to which the bracing bars were attached. The ends were not faced, nor was any lead or copper sheeting used in the joints. This seems to the Author to have been an unwise omission, especially for the central and the end piers, which had ultimately to bear the whole weight of the girders, for several cracks, running vertically from the joints, and from 6 inches to 30 inches long, made their appearance as soon as the load was put upon them. On the Bombay and Baroda railway, where columns are extensively used, the precaution is taken of filling them up with concrete, in such a manner that the load should bear entirely on the concrete.

The staging at the middle overhung considerably the foundation pit for the masonry pier, so that the columns for its support there had to be placed 14 feet out of the line of the others in the scaffolding, and raking struts of great strength had to be sprung from them. These carried the girders until the masonry was sufficiently advanced to allow the excavations around it to be filled up, when an extra column was put up, which took the bearing at the centre, and served ultimately as one of the props to the machinery for lifting the girders.

The two platforms were fitted with tramways communicating with the main line across the ravine, and the iron work of the girders was brought up from the nearest stations and distributed on the platforms during the night, when only the main line was available, and was put together during the day.

The girders, four to each span, were of the triangular kind, known as the Warren-truss, bearing the line on the top. Their total length was 206 feet, and the distance between the end pins was 202 feet. Their total weight was 812 tons, or rather over 100 tons each. The boom was a wrought-iron box, 2 feet 3 inches square, with an upper plate 3 feet 1 inch; the total section varying from 54 inches at the ends to 82 inches at the middle.

The truss was composed of a set of nine equilateral triangles, of 22 feet $5\frac{1}{2}$ inches to the side, tied together by a series of rolled iron links, 11 feet $2\frac{3}{4}$ inches long, $1\frac{1}{8}$ inch thick, and 8 inches deep, with steel pins 6 inches in diameter, and from 3 feet to 5 feet long. The total section of the links varied in the triangles from 36 square inches at the ends to 72 square inches at the middle. Owing to some difficulty in the manufacture of links 23 feet long, which was the length required, links of half the length were used, with consequently a double number of joints, and rods hanging from the boom to support the intermediate ones.

The struts and ties forming the web of the girder were of boiler plate, riveted in the shape of boxes, from 12 inches to 14 inches wide, 2 feet deep, and 22 feet $5\frac{1}{2}$ inches long. The working sections varied from 46 square inches at the ends to 27 square inches at the middle; but the ties in the three first bays were links, similar to those in the bottom chain.

In putting the girders together, the parts of the boom were laid in a straight line, and to a camber of about 3 inches in excess of the ultimate camber of 5 inches. The sides of the triangles were then slipped in from underneath, and fixed to each part, and were further joined at the ends

by the steel pins. The links of the bottom chain were afterwards put on these, and connected at the intermediate joint, generally a rather tedious operation in large girders, but here rendered easy by the great camber given to the boom, and the extra joint in the links. Then the parts of the boom were let down, till they joined closely together, and were riveted up. The connecting pins were driven by wooden rams, weighing from 5 cwt. to 6 cwt., generally in less than three hours; but in some cases when, through carelessness, any dirt was left in the hole, or scrapings remained in, the pin became jammed, and was not driven home in less than eighteen hours. Screw presses, specially designed for this work, failed entirely; as it was found absolutely necessary to give a blow of some kind.

In March, or about two months after the scaffolding was completed, the eight girders were ready to be hoisted on to the masonry; but as the latter was far from being finished, it was decided further to complete the superstructure on the building stages by fixing on the roadways, especially as it happened that the girders were designed originally for single line spans, so that the double line here required had to be made up of two independent bridges laid side by side. The roadways were therefore light, and each set was fitted with its own horizontal bracing, double stringers, &c. The weight thus added to some of the girders was 26 tons, being 112 tons with the roadways, and 86 tons without; but as the lifting chains were designed to bear in safety a load of 100 tons, their total section being 20 square inches, it was not thought that the excess of 12 tons over this would be in any degree dangerous.

This arrangement proved ultimately to be of great advantage; for the season was so far advanced when the girders were at last hoisted on to the masonry, that the opening of the viaduct must otherwise have been considerably delayed, for the rain fell so heavily and continually, that the men could not work half their time, and were with difficulty kept together at all, even to finish the small amount of work that remained to be done.

In order to raise the girders from the platforms on which they were built on to the masonry, and to lower them on to their bearings, a set of timber trestles, about 10 feet high, was fitted up on the pier and the abutments, of which the top balks projected sufficiently to plumb over the girders, and take a bearing on the columns that had been carried up from the staging to receive them; and the lifting machinery, which was fitted on a species of carriage, rested on these balks, and could traverse upon them.

This machinery consisted of a wrought-iron frame on wheels, to which was fixed a cast-iron press cylinder, fitted with a plunger 6 inches in diameter, which could move through a length of 2 feet, and from which the load was suspended by a cross head and two linked chains. There were two force-pumps, one on each side of the lifting plunger, worked by fifteen men at each end of a rocking lever in the usual way, the diameter being 1 inch with a stroke of 4 inches. The two chains were each of two bars 7 inches by $\frac{5}{8}$-inch, jointed at every 12 feet. They were fastened to the girder below by a cross bar, and short links keyed on to the last pin, and they were pierced at every 2 feet in their length, with holes, for stopper pins, 3 inches in diameter. On each side of the hydraulic ram, they passed through a hollow cast-iron standard, with slots in the sides, 9 feet 3 inches long, fitted to receive the stopper pins; so that the load could be transferred from the press plunger to these standards at the end of each stroke of 2 feet. The plunger being lowered, and pinned through to another division of the chain, was again forced up. This operation was repeated, until the girder was high enough to traverse over the masonry. A crab winch and tackle attached to each traveller then worked the girder along the trestles until it could be lowered on to its bed. The props which supported the trestles from the masonry were so arranged that they could be easily removed and put in again to allow the girder to pass.

The men worked at the rate of about twenty-five strokes per minute, and the speed of lift was about 12 feet per hour. The first girder hoisted was one of those upon which the roadways were fixed (weighing 112 tons), and it had to be packed up on the masonry about 10 feet above its ultimate bearing, until the second girder could be brought up, and traversed to its place under the overhanging roadways. This was done, and the packings being removed, the first girder was lowered on to its bearings, and its roadway bolted to the second girder. It required five days to complete these two operations. The third lift was a light one, and lasted a day only; and the fourth girder was also lifted and bedded in one day.

The hoisting machinery was then taken to pieces, and shifted to the girders of the second span, and the same operations were gone through and completed in four days;—or altogether in fifteen days after the work of hoisting had commenced.

Amongst the various hindrances that occurred were two that might have been of serious consequence:—Soon after the second lift had been

commenced, one of the pump-barrels of the machinery at the abutment end burst, leaking so much as to be entirely useless; and then, while working with a spurt, to keep up the same speed of lift with one pump only, the bearing of the rocking lever gave way, thus completely disabling one set of pumps. A spare set was, however, fortunately at hand, and the work was continued without much delay. In the second place, at the commencement of the first lift, just after the girder had been cleared from the staging, the end link of one of the chains was found to be split through, and opened out, evidently through an imperfect weld. The girder was lowered, and a new link put in. Upon the whole, the machinery worked well. It was simple and easily handled, and with more experience with it in the second span, each girder was raised the full height required, or about 63 feet, and traversed to its place in a day with hardly a single interruption.

The superstructure of each opening consisted of four main girders, 202 feet in the clear, and 22 feet 6 inches deep, with thirty-seven cross girders on the top bearing the platform, which was of planking 4 inches thick; and the rail timbers, with a double-headed steel rail, weighing 84 lbs. to the yard, and chairs 2 feet 6 inches apart. The main girders were placed directly under each line of rails; the gauge being 5 feet 6 inches, with the usual 6 feet space between the lines. They rested at the abutments on a frame-work of boiler plate, 1 foot deep, bolted to the masonry, and fitted with sliding beds; but on the pier the ends of the girders were securely bolted, so that they were free to expand only at the abutments.

About a fortnight after the last girder was raised, one line of rails was laid, and a train, consisting of seven engines, each weighing 55 tons, was brought on test the girders. The absolute load bearing on each clear span was 357 tons, or about 1½ ton per lineal foot of single line. The greatest deflection produced was 1⅝-inch, and the permanent set was rather under $\frac{1}{16}$ of an inch. The train was then run over at a speed of from 10 miles to 12 miles an hour, to test the lateral deflection and the steadiness of the pier, when very little motion was observed or felt in either case.

On the next day, the 1st of July, 1868, or nineteen days within twelve months after the first viaduct fell, the trains resumed their old route across the Ghâts.

The native workmen employed were principally riveters, sailors, and

laborers. The riveters were paid at the rate of 12*s.* per week, or 2*s.* per day, and each gang of three men and a boy averaged forty-five $\frac{3}{4}$-inch rivets per day. Upon the whole their work was moderately well done, but the cost amounted to about 14*s.* per ton of bridge work, or rather under 4*d.* per rivet put in. The native sailors, or khulasees, whose duty was specially to rig up the derricks and scaffolding, proved to be very useful, under English foremen, in fitting the girders together. They worked in gangs of about twenty men, under two native head men; their wages averaged 9*s.* per week, or 1*s.* 6*d.* per day. The total sum paid to them was at the rate of 39*s.* per ton of bridge work. The laborers employed were divided in two classes; those who worked the winches, and so on, receiving 4*s.* 6*d.* each per week, or 9*d.* per day, and those who worked as carriers, receiving 13½*d.* per day, the total sum paid to them being at the rate of 66*s.* 9*d.* per ton of bridge-work.

The expenditure for labor alone at the site of the works, during the twelve months which ended in September 1868, when the last portion of the building stages had been removed, and everything connected with the superstructure was completed, amounted to nearly £8,000. This includes a sum of about 65*s.* per ton, paid subsequently to the opening of the viaduct, for the removal of the stages. This amounts altogether to nearly £10 sterling per ton of bridge-work erected.

Several circumstances enhanced the cost of this work, such as, for instance, that the men were mostly hired during an exceptionally busy season, their wages ranging from 15 per cent. to 30 per cent. above the usual rates. Then the amount of work done was not so great as it might have been, in consequence of the backwardness of the masonry, and the frequent interruptions caused by the monsoon weather. Probably, under more favorable circumstances, this work could have been carried through at from 20 per cent. to 25 per cent. less cost.

There are about 4,000 cubic yards of solid masonry in the pier, and about 5,300 cubic yards of new work in the abutments. The total cost of this masonry was £36,100 sterling.

# No. CCLXXXVIII.

## GUNDUCK RIVER WORKS.

*Description of the Method employed in the River Gunduck, in Bengal, for the purpose of Deflecting and Training Currents, and of Protecting Banks from Abrasion.* BY T. B. STONY, ESQ., *Exec. Engineer, Irrgn. Branch, D. P. W.*

IN the latter end of 1868, one of the high freshes of the Gunduck burst the line of the Tirhoot embankment in two different places, at Ramdowlee and Lalgunge. A survey of these two reaches is attached to this paper [vide *Plates* XXX, XXXI.] It will be observed that the river at both these points flows round what, for a stream of the velocity and volume of the Gunduck, are very quick curves, the concave edges of which are lined by the embankments it is desired to protect; when, therefore, it was determined permanently to protect these points of the embankment from destruction, it was evident that nothing less than deflecting the whole stream towards the opposite bank would suffice.

The works which will be described were designed to oppose the force of a volume of about 2,70,000 cubic feet per second, flowing with a velocity on some occasions of over 7 miles per hour; moreover, they were exposed to the liability of such strain for 6 months, without chance of efficient repair, and were erected on a foundation as ill suited as possible for the purpose, being all either fine sand or the light silt deposit of the river. Neither was there any clay to be obtained which would not melt in water, nor was any kind of stone procurable in the vicinity. These considerations are not without importance, as under less unfavorable circumstances, there is no doubt the system recommended might be carried out in a

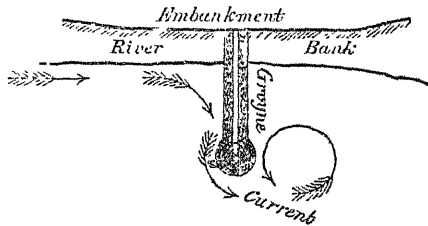
much cheaper, because in a much less substantial, manner, and with cheaper materials. The rise from summer to flood surface is 14 feet, and the depth of stream at low water is 10 to 12 feet, so that in flood the current has a depth of 24 to 26 feet.

The manner in which points, which the current threatens to erode, are protected, is shown in *Plate* XXXII., *Figs.* 1 and 2). It may be described as a self-adjusting screen which protects the side of a bank from being abraded or undermined. It is much in use in Italy and Southern India, and was first brought into use on the Gunduck by Col. O'Connell of the Royal (Madras) Engineers. It consists of a screen or frame of mats, stiffened with bamboos and firmly lashed to a line of piles, which are driven into the toe of the river slope of the bank. These piles are driven in obliquely so as to form a lattice work and make an open fork at top, where they cross each other and are nailed together. Brushwood is thrown in behind this screen loosely. Thus there can be no erosion on the slope of the bank, as the water cannot flow through the screen, and remains quite still behind it.

But the current, on being opposed and turned by the screen work, rushes along the face of it with increased velocity, and cuts away the ground into which the piles, which support it, are driven; and to prevent it being undermined and overturned, its upper edge is connected with the bank by long heavy palm trees, whose roots are embedded in the bank, and whose tops pass through and rest on the open forks in the row of piles described above. In this manner the frame of screen work is bound by the head to the bank, and prevented from falling over if undermined, or falling back from the thrust of the current.

But it still remains to prevent the screen work, when undermined, from letting the current in under it, and causing it to float up to the surface. This is done by forming a platform over the palm trees stretched out from the bank, and weighting this platform with earth or sand bags, so that, when the sand is removed from beneath the screen, the weight above continually keeps the piles pressed into the sand. In *Plate* XXXII., *Fig.* 1, the dotted lines show a screen, which has subsided 12 feet from its initial position, pressed down by the weight above, as the supporting material was withdrawn from below. "Snakes" formed of straw-ropes platted into a mat, filled with clay and made of a cylindrical form are used to protect the foot of the screen work outside from excessive erosion.

The whole of this protective structure costs not over Rs. 2-4 per foot run. It has been found a most efficient protection to banks exposed to severe eddies, but its use, in the writer's opinion, should be limited to the protection of the river banks, as when applied to the defence of groynes projecting into the stream, it is easily overthrown.

The next construction, and the most important of all, used in these training works, is the Groyne. This groyne is run out, at right angles to the direction of the main current, along low sand banks, and across small channels where it is desired permanently to turn the course of the stream, [*see* the groynes *b, b*, in *Plates* XXX., XXXI.] They are simply earthen bunds, except their heads; the earth being well rammed and turfed with long grass to break the roll of the waves on the slopes; and in places where the bund crosses hollows or channels, the toe of the slopes are piled. When a stream is opposed at right angles by a groyne, the head of the groyne becomes the new bank of the stream and the current bends out towards that point from some distance up-stream, and in the angle formed by the junction of the bank and groyne, the water is almost still. From this it

will be evident that the erosion and stream on such a groyne is chiefly confined to its head and a certain distance inwards from it, which distance depends on the angle the line of the groyne bears to the direction of the up-stream current; if it is less than a right angle, the distance effected will be less, but there will be *more* strain on the head; if it is more than a right angle, the distance exposed to abrasion will increase, until at about 130°, the stream will run along the entire length of the groyne and its whole length will require to be protected.

It is found that bunds formed of sand and turfed are quite strong enough for groynes with good heads, as there is but little pressure on them from heaping up the water on the upper side. The difference of level is seldom over 6 or 8 inches. The section used was 4 feet crest, and 2 to 1 slopes, and it was quite sufficient.

The head is the difficult part in a groyne. It is probable that the bed of the river may be cut 20 feet in a few days, which would

undermine any pile that could be driven into it; so that piles, although used, cannot be depended on by themselves for this purpose. They are now used in order to keep the whole structure of the head together, and and brace it both vertically and horizontally. *Fig.* 3 in *Plate* XXXII., is a plan of one form of head used successfully. It is composed of two rings of bamboo piling 15 feet apart, driven in a circular form round the toe of the slope of the groyne bund at its head. Inside these rows of piles, is packed brushwood facines in layers about 2½ feet thick, weighted down with sand bags. The bund is then thrown up inside this brushwood fence, and well rammed and consolidated, and by its weight serves to keep the brushwood round it pressed downwards and outwards, so that when it is undermined, as it is sure to be, the whole head sinks down in one mass and is built up again in the same manner. Of course, the head spreads out on all sides as it subsides, but that only gives it a firmer foundation, and, as in filling in from the top a slope is formed, the more the head sinks into the river the stronger it becomes. Care must be taken to prevent a chasm occurring when the head falls out, between it and the groyne bund. One of these heads was put in last year to protect a groyne which had been broken, there being at the time 31 feet of water immediately under the spot, and it withstood, during the length of the rains, the whole force of the river. This was the Ramdowlee groyne head [*see Plate* XXX., *b*, *b*.]

The small Nose shown on the groyne head in *Plate* XXXII., *Fig.* 3, is a contrivance for throwing the scour which takes place under the toe of the bund and round the head, further out, and where it was used, it prevented abrasion inside itself, and accumulated the force of the current on its own head. As long as it can be held it is of use.

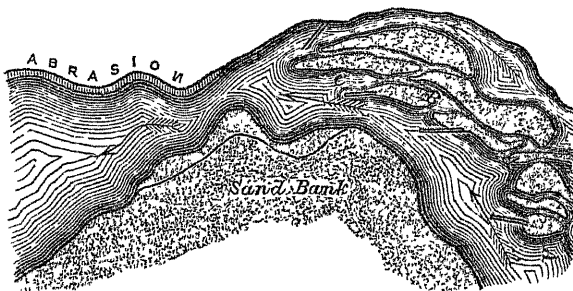
Light cold-weather spurs are constructed of two rows of bamboo piles 4 feet apart, and filled in with brushwood fascines weighted down with sand bags. They are not calculated to withstand the force of a

current, but are useful in training it at low water, and are erected on the tail end of shoals to encourage their extension. An example of this kind of work, constructed last cold season, is given in the sketch, A, B, C.

*Plate* XXX., is a survey of the Ramdowlee reach, in the Gunduck River, in December 1869. It will be seen that, in the preceding season, the stream ran along the left bank in the channel *B, B*; being driven across from the right bank by a point composed of kunkur clay at Thahara. In 1868, a breach had been made at Ramdowlee, and a deep wide channel scoured through the river banks and bund; and there is no doubt that, but for the protective works of 1869, the whole line of embankment from Rewah Tollah to Ramdowlee would have been carried away. The first thing done was to erect three strong lines of bunds across the breach line and to push forward the bank of the river to its original position of the year before, raising it to its normal height, and protecting with a line of the construction called "screen work," *e, e,* already described. A low water brushwood spur *d, d,* was thrown out just above the screen work to break the force of the current against it. Higher up, another brushwood spur *c, c,* was placed, to catch any eddies caused by the agitation and rush of water at the spur bund or groyne *b, b*; and a little above this groyne, was a small spur *a, a,* which it was found necessary to erect in order to prevent the current from cutting into the rear of the groyne, which it threatened to do at one time.

The groyne *b, b,* was the most difficult and important work of this system. It was thrown across a deep channel and along a submerged sand bank, and was composed entirely of sand, turfed with sods. It was the first work of the kind tried in this river, and its head was carried away four several times during the freshes. After great trouble and many different attempts to protect it, by sinking boats, screen work, and "snakes," it was, at last, thoroughly and effectively protected by a brushwood head, similar to that already described as a "groyne head." The water which was heaped up by this groyne rushed round its head with great velocity and scoured out a hole of over 40 feet in depth. This was filled in by constant layers of brushwood fascines and bags, which formed for themselves a natural slope. The price of head work may be estimated at Rs. 8 per 100 cubic feet, including sand bags, binding and sinking, and bamboo piling. This groyne caused to be formed the bank A, A, A, above and below it, the height of which, it will be seen by the section, is 25 feet, bringing its top to a level with the bank of the river. This sand bank

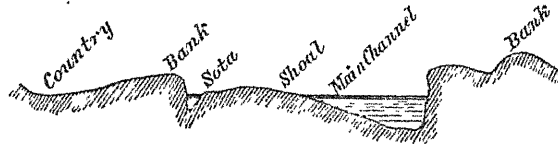
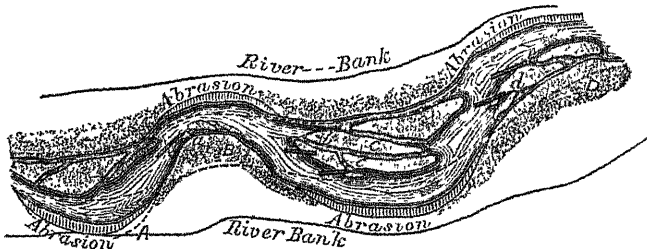
extended down to the shore of the breach and caused its mouth to choke up. The groyne should have been made longer had the season admitted, so as to drive the current across the river and on to the shoal marked $x$, $x$, on the right bank. This has since been done.

*Plate* XXXI., is a survey of the Lalgunge Reach of the Gunduck. In the form of the channel and the position of the point threatened, it is very similar to that at Ramdowlee. A high kunkur formation on the right bank leads the stream directed against the saltpetre Factory at Jahanabad. B, B, shows where the main stream ran in 1868. The water in high freshes spread over the Decarah, $y$, $y$; and in its endeavour to discharge itself through the narrow channel, opposite the Saltpetre Factory; rushed with great force round that point and scoured out the ground immediatly under the slope of the bund to a great depth. A spur bund was thrown across the low land of the Deearah, made entirely of sand, and a head was made to it, which although carried away three times, was at length rebuilt in the way done at Ramdowlee. This groyne, it will be seen, has produced a great effect on the direction of the stream, causing it to cut away the shoal $x$, $x$, on the right bank, and to deposit larges sand banks A, A, A, at the threatened point. The width of this sand bank near the factory is 2,000 feet, and its height (*see* section) is 16 feet.

It is a mistake to suppose that intermittent attempts at controlling rivers of this description are sufficient. Works of this nature should be permanent, if the protection is to be permanent. No extent of shoals or sand banks can be depended on for one season, as a protection. A mile in length and half a mile in breadth can be melted and carried off in two days if the river set on it. It is, therefore, necessary to have them repaired, extended or modified every season; there is no such thing as turning a river of this sort once for all, and then leaving it safe.

Cold-weather training works are also continually necessary, because at that season, the high water groynes, &c., are high and dry, and do not control the stream at all; and it has happened that all the benefit accruing from their action has been destroyed by the stream in the low season, which, being a small volume and of greater velocity than the freshes, runs in and out among the high water spurs without being in the least controlled by them, doing great mischief. Low-water brushwood spurs, as already described, are used for this purpose: they cost from Rs. 2 to 2-8 per foot run, driven and filled with brushwood. This description of

work is of great value in training a large stream, as it is found that the direction which the main stream takes in the cold season will be almost exactly the same as that which, if let uncontrolled, it will generally keep during the floods.

But, for cold weather spurs to have much effect, they should be commenced two or even three reaches above the point to be protected. These deltaic rivers (as is well known), whose large silt laden volumes flow with small velocities, in wide beds filled with sand, are always serpentine in their channels. Their streams are continually engaged, while forming a shoal above on one side, in moving away another shoal below on the other side; and, having carried it a short distance down the channel, depositing it again in another shoal; so that there is always one shelving and one steep bank, the former silting and advancing, the latter abrading and receding.

The section below shows the normal section of a deltaic river channel. The cutting, except where some obstacle restrains and checks the stream, such as a sunken boat or a spur head, is almost always done by the edge of the current and not by the bottom of it, and thus the greatest alteration in direction of the channel take place when the river

is falling or rising and low, and not when it is full. It appears desirable from the experience gained in these works, that all training or protective works should be placed on the shelving bank as shown in this sketch This is not so difficult to do as may appear at first. The silting and the abrading banks are always alternate and reciprocal, as in this sketch.

Suppose A is the point to be protected; instead of placing a work at or near A, it would require one of a slighter construction, and be more efficient at c, its reciprocal silting bank, by which the point above it would be removed, and the channel take the direction of the dotted lines. The higher up this system was continued from the threatened point, the better; and, indeed, there is no doubt, to train a river effectually and easily, not isolated spots, but its whole course should be controlled.

It is to be regretted that more has not been published of the experience of Engineers in dealing with Indian rivers. There is no settled system to work by; each authority has a different method, while some experienced Engineers give their deliberate opinion that such work as the control of Deltaic rivers cannot be carried out with success at all. In the case of the Loodiana crossing over the Sutlej on the Delhi Railway, the papers on which were lately published by the Government of India, we find all the resources of an experienced staff of Engineers for some years, fail, not only to turn the river, but to keep it in the channel it was in. In this case many of the conclusions formed by experience in the Gunduck are corrborated. "The uselessness of this" system (of piling), says Mr. Harrison, the Chief Engineer, in his report "is shown," for when the river came "against the work, it at once scoured to a depth of 30 feet, which was 6 or 8 feet lower than piles can be driven." The only construction which seems to have stood any time in the Sutlej were the hurdles thrown into the bed of the stream by Mr. Anderson, Executive Engineer, Grand Trunk Road, which, he says, when once sunk, were never moved.

Mr. Leonard, C.E., in his well-known able report on the Training of the Hooghly, mentions a brushwood spur used on the Vistula and Danube, in Austria, with great success. It is composed of rafts of brushwood made of fascines, strongly lashed together, about 3 feet in thickness, and 20 to 30 feet long by 10 to 15 broad, the centre of which was filled in with stone, good clay, or sand bags, and the rafts were then sunk on the site of the spur, one over another, until the spur reached the water level. This is nearly the same method used in the Gunduck, and is much cheaper than any other that has been tried, and the only protection that is known, that can be depended on to last through the season.

T. B. S.

*July 29th*, 1870.

# No. CCLXXXIX.

## THE SOANE CANAL.

*Memorandum by* H. C. Levinge, Esq., *Chief Engineer, East India Irrigation and Canal Company, on the project for a Canal from the Soane in Behar.*

*Datum.*—The datum used is that which was adopted by Colonel Dickens in his Soane Canal Project, making the low water-level of the Soane at Dehree about 300·00. In the present stage of proceedings, this is obviously the most convenient datum to refer to, but I purpose next cold season connecting it with the levels taken along the Railway by the Great Trigonometrical Survey Department, and reducing the whole to mean sea-level. From a trial-line run from Chunar to Dehree, it would appear that the Soane low-water at that place is 343·60 feet above the Railway datum, North Western Provinces, and 326·60 feet above mean sea; but as the levels have not been checked, this requires verification.

*Anicut.*—After mature deliberation, the position determined upon for the anicut is 2,000 feet above the causeway at Dehree; to have placed it further up would have entailed greater length of canal, and greater fall to be overcome without any additional advantage, the area of land left out of irrigation being very small. The level of the bed of the river at the place selected may be taken at 301, and the anicut being 8 feet high, the level of its crest will be 309·00. The length between the abutments is 12,550 feet, or 2·35 miles; it will be provided with three sets of under-sluices as shown on the drawings, each 500 feet in length: one set on either flank, and one set in the centre of the river. The drawings show

the latter only provided with folding back-shutters in bays of 50 feet, but should the experiment with these shutters now being tried at Cuttack, in the centre sluices* of the Mahanuddy Anicut prove successful, I purpose substituting them for the ordinary ones on both sides. There can be no question as to their much greater efficiency, the numerous piers in the ordinary sluices proving a great obstruction to the flow of the water.

*Discharge of Soane.*—From a careful cross section of the river taken at Dehree, and from the reliable flood-level of September 1864 (the highest on record), cut on the cause-way at Baroon, the discharge of the river has been ascertained to be 1,026,172 cubic feet per second; the mean depth at highest flood being 11·64 feet, and the breadth between the banks 12,400 feet.

*Calculation of discharge over weir.*—The depth of water over the weir in times of highest flood will be $6\frac{1}{2}$ feet. From the formula, $D = 3{\cdot}5 \times l\, d\, \sqrt{d + {\cdot}035 w^2} + 8{\cdot}02 \times l\, d_2\, \sqrt{d + {\cdot}0153 w^2}$, the afflux will be found to be 1 foot 3 inches. The momentum will be less than one-half of that at the Naraje Anicut, and five-eighths of that at the Mahanuddy Anicut at Cuttack.

*Head-sluice.*—The head-sluices on either side are designed to discharge 4,500 cubic feet per second, with a head of 4 inches, and depth of water 9 feet; they consist of 24 vents of 6 feet wide each; the shutters will be raised by a traversing hoist, the design for which has not been prepared as yet.

*Head-locks.*—The locks are to be 150 feet in length, and 20 feet in width inside the chambers: full particulars are shown in the drawings.

*Western Main Canal.*—This canal, destined to convey irrigation water to the District of Shahabad, will have to carry up to the place, where the Arrah Branch is thrown off, 4,500 cubic feet of water per second for the irrigation of 1,200,000 acres: this at first sight may appear a small quantity for the irrigation of so large an area, but it must be recollected that only about one-half is cultivated with rice. The greatest demand for water is likely to be for the rice-crop; and to convey sufficient for this the canals are designed, the supply in the river at the time of the rice cultivation being always abundant.

*Dimensions of canal.*—The dimensions of the canal at starting will be as follows:—Breadth at base, 180 feet; depth of water in full

* *See* No. CCLXII., of these papers, and Correspondence in the present Number.

supply, 9 feet,* fall per mile, 6 inches; side slopes, 2 : 1; at the 5th mile, the Arrah Branch will be thrown off, taking one-third of the whole, or 1,500 cubic feet per second, leaving 3,000 cubic feet per second to be carried on to the 12th mile, where the Buxar and Chowsa branches will leave the main line. From the point where the Arrah Branch is thrown off, the breadth of the canal will be reduced from 180 feet at base to 124 feet, the fall and depth of water being the same. The Buxar and Chowsa branches will take off 1,256 cubic feet per second for the supply of 335,000 acres; the quantity remaining to be carried forward by the main canal, therefore, is 1,744 cubic feet per second; the width of canal will be reduced to 100 feet base, and the fall to 1½ inch per mile.

*Length marked out.*—The canal has been staked out to the 21½ mile, or as far as the crossing of the Grand Trunk Road west of Sasseram. In laying out this part of the line, the first object to be attained was to get out of the deep cutting at the head as quickly as possible, and bring the water on to the surface, and then to follow the contour of the country: hence the detour that it has been necessary to make. Great care and trouble have been taken in ascertaining the best course for the canal, and an elaborate series of cross-sections of the country were made before the line was finally decided on.

*Arrangements for regulating level of water in canal.*—As the ground falls rapidly soon after crossing the road, it will be advisable, in order to avoid a long circuit which would have to be made if the contour were followed, to construct a lock on the main line of canal somewhere near the Koodra; probably just beyond it will be the best place, so as to keep the advantage of level to cross that nullah. At this lock, a waste-weir must be constructed, the level of the top of the boarding on which will be 306·00 above datum. The object of this is to impound the water for navigation when necessary, so that, when the supply coming down the canal is small, there will always be 5 feet on the sills of the head-lock. It is obvious that the top of the boarding of the waste-weirs of the first lift-lock on each of the branch canals to Arrah, Buxar, and Chowsa must be of the same level; the boarding on all these weirs will be removable, plank by plank, so that the level of the water can always be regulated ac-

* The greatest demand for water will be during the rains, as above stated, at which time there will always be at least one foot of water running over the Anicut; and, therefore, 9 feet of water in the canal.

cording to the supply coming down, the length of the weirs being calculated to discharge the full quantity at 4 feet in depth running over the crest.

*Cutting at head of canal.*—It will be seen, by a reference to the section, that the cutting at the head of the Western Main Canal is very heavy, and that the water will not reach the surface till the 5th mile of the canal is passed; it is intended, therefore, at first to excavate the canal with a base of 50 feet only, so as to get the water out on the surface as early as possible, according as the branches are extended; hereafter, the head of the canal can be widened.

*Course of canal beyond Sasseram.*—As the levels from Chunar have now been connected up to the Soane at Dehree, the fact has been established that the level of the country at the foot of the hills at the former place is 50 feet below the bed of the river at Dehree. The course of the canal is clearly defined; skirting the foot of the hills the whole way, passing south of Chynepore, and through the rocky pass at Ghate Bhurganwan, it will cross the Kurumnassa near Kysoa, and drop into the Jurgo near Chunar.

*Drainage crossed.—The Kao.*—The principle drainage on the first 21½ miles of the Western Main Canal is the Kao: this nullah is subject to violent floods, as may be expected from the rocky nature of its catchment-basin; there is a curious feature in this stream, viz., that before emerging on the plains, its water in times of high flood divides into two portions: one formiug the Koodra runs westward, passing south of Sasseram, while the main stream of the Kao continues its northerly course: the Koodra seems to be an escape, the level of its bed being much over that of the Kao in times of high flood. About one-third of the whole stream, I should say, finds its way into the Koodra. I have thought it right to disregard this overflow, and provide water-way for the whole area drained by the Kao. The calculations for the area of water-way are founded on the supposition that two-thirds of a rain-fall of 9 inches in 24 hours will have to be carried off through the arches in that time, at a velocity of 8⅓ feet per second. The area of the catchment-basin of the Kao above the canal crossing is 57 square miles, so that 1,103 square feet of water-way will be required, or, say, 20 openings of 54 square feet each.

*Description of syphons.*—From the level at which the stream is crossed, it will be necessary to put in syphon culverts, and as the stone in the

neighbourhood is so magnificent, and procurable in suchlarge blocks, I purpose covering the syphons over with flat stones instead of arching, securing the stones to the foundations by holding down bolts.

*Width of canal.*—The width of the canal over the syphons will be reduced to 90 feet, which will give a velocity of about $3\frac{3}{4}$ feet per second.

*Bed of Kao below syphon to be lowered.*—In order to insure a better discharge through the syphons, I purpose lowering the bed of the Kao about 2 feet on the down-stream side, continuing the excavation for some distance down. The necessary levels for this have not as yet been taken.

*Other drainages, inlet, and escape at 5th mile.*—There are no other drainages of any importance to be provided for. An inlet and escape will be constructed at the 5th mile of the canal, just beyond the off-take of the Arrah Branch: this will drain as near as I can ascertain 5 square miles of the flat country; and, as the cultivators impound most of the water falling on the plains for irrigation, I consider it will be sufficient to allow for a rain-fall of $\frac{1}{4}$ inch per hour being carried off; this will give a length of weir of 40 feet, the water running 2 feet deep over the crest. It will be observed that the level of the ground is almost the same as the canal water; and as that entering the canal from the fields is only surface rain-water, no silt will be carried in.

*Design for inlet and escape.*—I have designed a drop-wall and floor, but such is hardly necessary. If the bed slopes of the canal were paved with rough stone, it would be sufficient protection against erosion; but as piers and abutments must be built to support the bridge for the towing path, the addition of the drop-wall will be but trifling.

*Inlet and escape at the 12th mile of canal.*—Another inlet and escape precisely similar will be built at the 12th mile of the canal.

*Two syphon culverts.*—Two syphon culverts of four arches each, of the same dimensions as the Kao Syphon, will be constructed at the 870th and 1100th chain of the canal, respectively, to carry off the drainage-water between Sasseram and the canal.

*Bridges—Rhotas Road Bridge.*—The head-way under all bridges on the various canals will be 15 feet. The first will be built to carry the Rhotas road over the canal at the 23rd chain; it will consist of 3 spans of 50 feet each, with a road-way 15 feet wide between the parapets.

*Other road bridges.*—The same design, will answer for the Sasseram and Nassreegunge Road at 300th chain, for the Sasseram and Arrah

ram and Arrah Road at the 845th chain, and for the Sasseram and Buxar Road at the 999th chain, and for any other second class roads that it may be found necessary to carry over the canal.

*Grand Trunk Road Bridge.*—For the Grand Trunk Road Bridge, a similar design has been made, the width of roadway being 20 feet instead of 15 ; this is the width of the large bridge now being built at Sherghotty by the Public Works Department. The canal crosses the Grand Trunk Road at one mile from the head at an angle of 61°; instead of diverting the road, I have designed a skew-bridge, and considering that building material is so good, there will be no difficulty in constructing it, though the angle is somewhat sharp.

*Eastern Main Canal.*—The Eastern Main Canal has been laid out for 10½ miles only : it has been designed to convey water for the irrigation of the whole area to Monghyr, and to that place it must some day be extended, though at present the limits are restricted to Patna. The area of country to be supplied with water being about the same as on the western side of the Soane, the canal will be constructed of the same dimensions, depth and fall per mile.

*Patna Branch.*—The Patna Branch will be thrown off at the 4th mile of the canal, and will take 1,500 cubic feet per second for the supply of 350,000 acres.

*Eastern Main Canal, 4 to 10½ miles.*—From the 4th to the 10½ mile the dimension will be, base 124 feet, depth 9 feet, side slopes 2·1, fall per mile 6 inches.

*Poon-Poon.*—The principal drainage to be crossed is the Poon-Poon; the place selected for crossing has been carefully determined with reference to the following considerations; *first,* that the highest known floods of the Poon-Poon should not rise on the masonry of the aqueduct above the level of the bed of the canal; *second,* that the embanked approaches to the aqueduct should not be unduly high; and *third,* that the stream should be crossed at a convenient place, and square to the line of canal; to attain these objects it has been found necessary to make a considerable detour, and to go below the junction of the Byturnee and Poon-Poon.

*Size of aqueduct.*—The area drained by these two rivers above the crossing of the canal is 374 square miles, and water-way to the extent of 7,240 square feet should be provided to carry off two-thirds of a rain-fall of 9 inches in 24 hours (as much as is likely to fall over so large a catchment-

basin in that time) at a maximum velocity of $8\frac{1}{3}$ feet per second; this will give 17 arches of 30 feet each; in allowing 20 therefore, ample provision has, I think, been made.

*Foundations.*—The foundations of the aqueduct will probably be found to be hard clay, but this cannot be positively determined till a careful examination of the bed of the river has been made and trial-pits sunk; should it on examination turn out to be sandy, wells will have to be sunk.

*Width of canal over aqueduct.*—The canal will be reduced to 90 feet in width over the aqueduct, as in the Kao Syphon on the Western Main Canal.

*Drainage near Baroon.*—The small nullah that is crossed and re-crossed by the canal near Baroon will be diverted into its old course by a new cut, and will be passed under the Grand Trunk Road by a bridge of three 10-feet spans. The present bridge consists of 3 fifteens, which is unnecessarily large for the area of country drained by the nullah.

*Drainage for bank of Soane.*—The drainage water from the high ground on the bank of the Soane will be passed under the Patna Branch Canal by a syphon culvert, and led into the Poon-Poon by a side drain parallel to the main canal.

*Arrah and Patna Branch Canal.*—Neither of these canals has been staked out, though their course has been determined, the Arrah Branch to near Nassreegunge, and the Patna Branch to Daoodnuggur. The position of the first lift-lock in each has been fixed, so that there will be no delay in submitting the plans as soon as the necessity for so doing arises.

*Quarries.*—The position of the quarries has been selected, and the line of tramway surveyed and levelled. It was at first contemplated to open the quarries at Muhesdeeh, but on trial, the quality of the stone turned out to be inferior; it was, therefore determined to revert to Dhadhand,—a well known quarry, where the stone is of excellent quality, and can be had in blocks of any size and thickness.

An experimental opening is now being made on the face of an outlying hill in the line of tramway to Dhadhand, and it is expected, from what has already been seen, that the stone will turn out of good quality. Being only 5 miles from the anicut, I purpose getting the great mass of rubble stone from there, and the cut-stone only from Dhadhand, which is $1\frac{1}{2}$ miles further.

*Land required for bungalows.*—I purpose taking up on the western side

of the Soane the strip of land lying between the river and the Rhotas Road, extending from the head-lock channel to Bustipoor. This is the land formerly occupied by barracks, and is, I understood, the property of Government; it will be purchased by the Company, and be occupied by bungalows, workshops, offices, &c.

On the eastern bank of the Soane, a smaller piece will be taken up for bungalows, which it will be necessary to construct for the Officers and Subordinates in charge of the works on that side.

H. C. L.

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*Extract from Note by Officiating Inspector General of Irrigation Works, Dated 8th September*, 1869.

The actual amount for which sanction is solicited is Rs. 52,80,870, exclusive of plant; made up of the following items:—

| | Rs. |
|---|---|
| Anicut and head-works, ... ... ... ... ... | 21,07,700 |
| Eastern Main Canal, ... ... ... ... ... | 10,26,980 |
| Western " ... ... ... ... ... | 15,60,550 |
| Tramway, ... ... ... ... ... | 1,55,640 |
| Bungalows, workshops, offices, store-room, &c., ... ... | 4,30,000 |
| | 52,80,870 |

As the Government is well aware, the Soane Project was originally drawn out by Colonel Dickens. The Irrigation Company, on taking it up, expressed the strongest desire to extend its limits as far as Mirzapoor on the west and Monghyr on the east. There was a long correspondence on the subject, which ended in the Company accepting the smaller scheme, not however without an expression of their "belief that its extension in the manner they desire will assuredly ere long be granted to them."

In regard to the designs for the works now proposed for the irrigation of the country from Chunar on the west, and to the River Morhur and to Patna on the east, I may explain that the alignment of the several branch channels does not differ to any great extent from that arranged by Colonel Dickens. The site of the dam across the Soane has been fixed 15 miles below the site selected by Colonel Dickens, and the western main channel, instead of being confined to navigation only beyond the head of the Sasseram branch, as that Officer proposed, is to be adapted for irrigation purposes also.

The whole area under command will be about 3,600 square miles according to Colonel Rundall's calculation, of which 2,400 are on the west, and 1,200 on the east bank.

The area comprised in Colonel Dicken's Project amounted to 2,033 square miles on the western bank, and 1,322 on the eastern; the excess by the present project being mainly due to the extension of irrigation provided for by the western main channel.

The culturable area is taken at 500 acres per square mile, and it is proposed to give the channels capacities suitable for the supply of half this area during the monsoon; that is, for about three-eighths of the whole area, at the rate of one cubic yard per hour per acre, or one cubic foot per second for 133 acres.

The designs for the masonry works seem to me to be remarkably good. The anicut is planned on the model of the one at Cuttack, which, I believe, has stood well. The Soane differs from the Himalayan rivers generally in being confined within a permanent channel, so that no flank defences of any importance will be required. No information has been given of the character of the sands* whether they are coarse and quartoze, or fine like the sand of the Ganges. But if any settlement in the rough stone-work takes place, the cost of replacing it will not be great. The length of the work will be $2\frac{1}{3}$ miles, and the estimate, exclusive of contingencies, amounts to about Rs. 14,00,000, or about Rs. 110 a foot, which I consider very moderate.

Colonel Strachey has questioned the necessity for providing a central set of under-sluices. Colonel Rundall wishes to retain them as they will afford considerable help in preventing an accumulation of sand above the dam, and in filling the lower bed more quickly on the rising of the early floods, thereby tending to reduce the overfall, and so lessening the trial on the apron. I would let these sluices stand, as it would be easy to fill them in if they proved unnecessary, while, it would be extremely difficult to add them afterwards if they were omitted now, but the regulation of the supply to the channels on the right and left banks will, I fear, prove a troublesome operation, and with so great an interval between them. There is, however, no possible way of meeting difficulties of this kind beforehand, and I can suggest no improvement on Colonel Rundall's arrangements.

* At the site selected by Colonel Dickens, the sand is described as coarse and shingly (page 35, Report).

under-sluices with small vents to those with 50 feet bays. The experi-
In a late note on the Damoodah project, I mentioned that I preferred
ments which were to have been made at Cuttack with folding shutters for vents of the latter size, will settle this point before the works at the Soane can be far advanced.

The designs for the head sluices and locks are, I think, all that can be desired except that return walls should be added in rear.

It may be taken for granted that a register of the rise and fall of the river is being kept up regularly, and that the supply available at different seasons will be ascertained with accuracy.

Colonel Strachey pointed out that the design for the Kao drainage syphon was not a safe one; and he referred to a work of similar design on the Kistna District which had failed. In reply it is stated that there is no *danger* in this kind of work, and that there are similar works in operation on the High Level Canal from the Mahanuddy which answer their purpose successfully. The slope of the Kao is not mentioned, but the drainage area is only 24 square miles, and a liberal allowance of water-way has been provided. The design is arranged on the principle of the work above-mentioned in the Kistna, on a river with a slope of 8 or 10 feet a mile, and a drainage area of several hundred square miles, and of one of the works near the head of the Ganges Canal, which also failed in exactly the same way, that is, the floods filled the artificial cutting with sand in a single season*. As Colonel Rundall had tried different modifications of the line of western canal in view to obtaining a better plan for crossing the Kao, but without success, the present design may, I conclude, be accepted. A large saving on the estimates may, however, be effected if brick arches are substituted for the proposed cut stone work, and the same remark applies to two other syphons of a similar pattern on the western main channel.

Five bridges are allowed for the first 21½ miles of the western channel and one for 10½ miles of the eastern channel, exclusive of the sluice-bridges at the heads. This allowance seems to be sufficiently liberal.

J. C. A.

* Sir P. Cautley's Report, Vol. I, page 156.

# No. CCXC.

## PUBLIC LATRINES IN CEYLON.

### MEMO. BY GUILFORD MOLESWORTH, ESQ., C.E.

OWING to the absence of a special caste in Ceylon to perform duties connected with latrines, (and the strong repugnance entertained by the natives of Ceylon to any duty of the kind,) it is almost impossible to carry out in Ceylon the latrine system adopted in India; and this difficulty complicates the question of sanitary arrangements to an extent which is scarcely intelligible to those who have had no experience in Ceylon. No threats, fines or dismissal, will induce men to attend properly to latrine work.

In designing latrines for public or prison use, my aim has been :—

1st. To adopt a form from which the products may be removed with the least possible amount of handling.

2nd. To be able easily to remove everything from the latrine, leaving it a mere shed, which may be swept, whitewashed, and otherwise purified without difficulty.

3rd. To obviate the revolting and degrading indecency which is usual in the public latrines at present in use.

4th. To arrange screens in such a manner that they cannot easily be soiled.

5th. To arrange the compartments so that it is almost impossible to use any portion but those intended for such use.

6th. To adopt a material for the floors which will not absorb moisture, and will be capable of being thoroughly cleansed.

7th. To allow of complete supervision of the latrine whilst in use without sacrificing decency.

The latrine which I have designed with these views is explained by the accompanying drawings.

The latrine consists of a shed raised to a sufficient height to allow small hand-carts to run under it on a short tramway; these carts are provided with self-acting locking bolts, so that when one cart is pushed in behind the rest, the bolt couples it to the preceding cart, thus forming a continuous train of carts which receive the deposits from the compartments.

The ordinary latrine is designed for four carts, or 16 compartments, but it is capable of extension to any length. Each cart is furnished with a projecting plate which overhangs the next cart, so that nothing can drop through to the tramway below. Each compartment is just large enough to receive a man, and its floors is raised one step from the floor of the passage—the screen does not extend quite down to the floor of the passage, so that any one can be seen from outside whilst he is in the passage, but not whilst he is in the compartment. The floor of each compartment is of cast-iron, sloping inwards towards the carts with a drip which leads any fluid from the floor into the carts and prevents it from trickling down the wall.

The sides and backs of the compartments are not carried down to the level of the floors, but sufficiently low for decency; and the posts which support them are fitted into sockets cast into the floor plates so as to raise them above the floor level.

The accompanying rules, framed for the guidance of the officers in charge of the latrines, explain the use of the latrine. The separation of the urine from the fæcal matter at one time engrossed my attention, and might easily be accomplished, as shown by *Plate* XXXVI., by giving the floors of the compartment a cant outwards to a channel cast in the floor plate, which discharges into gutters below; but, after careful consideration of the question, and observation of the results of those cases in which separation had been attempted, I arrived at the conclusion that the disadvantages of separation outweighed its advantages, and that a liberal supply of earth gave more satisfactory results.

## DESCRIPTION OF CART LATRINES ON THE DRY EARTH SYSTEM, AND RULES TO BE OBSERVED BY OFFICERS IN CHARGE OF THE LATRINES.

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The cart latrines are divided into compartments with cast-iron floors—one compartment should be boarded in as a receptacle for dry earth.

The back of each compartment is open for fæcal deposits into the latrine carts.

There should be a spare cart to every latrine.

The carts should invariably be emptied once a day.

The latrine should never be left without its full complement of carts.

When it is desired to remove a cart, the spare cart should be pushed in behind the other carts, so that the locking bolt of the preceding cart may couple it to the train.

The train of carts should then be pushed forward until the second cart takes the place of the first.

The locking bolt of the first cart should then be lifted so as to detach the first cart from the train, and enable it to be wheeled away and tipped into the pit allotted for the deposit of its contents.

When it is brought back empty it is to be pushed in (when required) behind the other carts as before described.

A layer of dry earth about 1½ inches thick must be spread evenly over the bottom of the cart before it is pushed into the latrine.

The prisoner or attendant whose duty it is to look after the latrine should be made responsible for its cleanliness in every respect.

He should be furnished with a bucket and scoop, with which he should scatter dry earth over the deposits as soon as they have been made.

When the cast-iron floor is soiled, the attendant should sprinkle a little dry earth over the part soiled, and when it has had time to absorb all moisture, sweep it into the cart.

The attendant should see that no one is skulking in the latrine or using any portion except the compartments. The screen is left open at the lower portion, so that any one not actually in a compartment can readily be seen from the outside.

Care should be taken to keep the earth dry.

The locking bolt, as well as the axles of the cart, should be oiled once a week, to keep them in good order.

The cart should be tarred inside and outside once in six months, after having been previously scrubbed with dry earth.

The cast-iron floors of the latrines should be periodically scrubbed with dry earth.

The latrine should be white-washed once in 6 months.

The tramway should be swept out occasionally.

J. L. M.

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# No. CCXCI.

## BRAKE POWER ON RAILWAYS.

By J. H. E. Hart, Esq., *Executive Engineer, Bombay Reclamation Works.*

Brakes, on the rolling Stock of Railways, are mechanical constructions by which blocks of wood or metal are pressed against the tires of the wheels; skids or slippers are inserted between the wheels and the rails; or by which sledges are pressed down on the rails.

Their object is to substitute the greater resistance of sliding for rolling friction, in opposition to the motion of the carriages.

Various methods of bringing brakes into action have been designed, such as levers applied directly by the hand;* levers combined with screws† or wedges;‡ chains, ropes or shafting connecting the brakes of several carriages, so that they shall act simultaneously;§ and the pressure of steam;|| also self-acting constructions in which the cessation of the drag of the locomotive,¶ or the recoil of the buffer-rods, serves to apply the brakes.

*Tire brakes* are usually made of soft wood, such as Elm, Beech, Poplar, Willow, &c., but they wear quickly, and sometimes burn; iron and steel has therefore been substituted with advantage for wood in the brake blocks on some of the French lines.

Tire brakes are uniform and gradual in their action; but they make the tires wear rapidly, causing the wheels to become polygonal; they

* The old hanging brake.
† Goodnow's.
‡ Stilmant's.
§ Ambler's, Newall's, Fay's, &c.
|| McConnell's.
¶ Davis', Guérin's.

also often cause a dangerous amount of heat, while they produce a jarring sensation in the carriages by interfering with the action of the springs; they are also liable to cause accidents through fracture of the gear.

*Skid brakes* are those in which a slipper or shoe is introduced between the rail and tire, so that the wheel mounts thereon. Their action is too sudden, and they cannot be removed without complete stoppage of the train. They are represented by Handley's brake.

*Sledge brakes* are those in which a sledge-shaped piece of iron or steel is pressed down on the rails; this is done in Adams' brake by levers, and in McConnell's by steam; the latter is of course applicable only to engines. These brakes are slow in action when applied by hand, and require enormous power to render them effective.*

*Plate* XXXIX., shows several brake arrangements and constructions. Besides the above brakes, properly so called, the arrangement by which the wheels of a locomotive are made to revolve more slowly than the speed due to the velocity of the train may be mentioned. This effect is produced by, what is termed, "reversing" the engine, because ultimately the tractive power of the engine is reversed, and consists in reversing the valve gear by which the action of the piston is inverted. This proceeding is very destructive to the machinery, and is never adopted except in cases of great energency.

The resistance to the motion of a train by its brakes may be less, but cannot be greater, than the friction of the retarded wheels on the rails and the value of a system of brakes will depend on the expedition and completeness with which it is able to convert all rolling into sliding frictions.

An absolutely instantaneous conversion is highly undesirable, and the best system will be that in which the brake can, at will, be applied gradually or quickly, to a few carriages, or the whole train, as occasion may demand.

It is found in tire brakes, that greater retardation is produced if the brakes are not pressed hard against the wheels during the whole time required for stopping a train; and it is also less injurious to the rolling stock and permanent way if the wheels be nearly retarded, not actually stopped, by the brakes.

The number of brakes which should be attached to a train will depend

* For a description of varieties of Brakes, *see* Spon's Dictionary of Engineering.

on the speed of the trains, and the gradients of the line; but it appears that in France, besides the engine brakes, 1 brake-carriage is allowed to every 7 carriages or less.

In Prussia $\frac{1}{6}$ the total number of the wheels of a passenger train on ordinary gradients, and $\frac{1}{4}$ on steep gradients, must be braked.

The distance a train will run on a Railway is found by equating the "actual energy of the moving mass, before the brakes are applied," with the sum of the resistances to motion; in other words, the distance run is as many times greater than the height due to the speed, as the moving mass is greater than the total resistance.*

Let $W$ = total weight of train in pounds or tons.
$g$ = acceleration of gravity, in feet per second = 32·2.
$v$ = speed of train, in feet per second.
$R$ = retarding forces, *in same units as* W.
$s$ = distance the train will run in feet.

The energy stored = half the *vis viva* = $\frac{W}{g} \times \frac{V^2}{2}$, and this is equal to the work done by the retarding force = $R\,s$, therefore

$$R\,s = \frac{W\,v^2}{g\,2} = \frac{W\,v^2}{64{\cdot}4} \quad \text{.........................(1)}$$

and

$$s = \frac{W\,v^2}{64{\cdot}4\,R} \quad \text{.........................(2)}$$

When trains are on inclines, the effect of gravity, in accelerating or retarding them, must be taken into account. If $i$ be the inclination of the plane to the horizon, the effect of gravity down the plane is $W \sin i$; in this expression

$\text{Sin}\ i = \frac{\text{height of plane}}{\text{length}} = \frac{\text{rise in feet per mile}}{5280} = \frac{1}{n}$, when the rate of inclination is 1 in $n$.

Equation 2, which represents the case of a train on the level, becomes for inclines

$$s = \frac{W\,v^2}{64{\cdot}4\,(R \pm W \sin i)} \text{ or } \frac{W\,v^2}{64{\cdot}4\left(R \pm \frac{W}{n}\right)} \quad \text{.................(3)}$$

the sign + or − being used according to whether the train ascends of descends the incline.

In practice, the speed of trains is usually expressed in miles per hour; therefore, if V stand for the speed in these units, $V = \frac{3600}{5280}\,v$

$\therefore\ v^2 = 1{\cdot}467^2\,V^2 = 2{\cdot}15\,V^2$; whence, equation (3) becomes

* Rankine.

$$s = \frac{W V^2}{30\left(R \pm \frac{W}{n}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

R should be made to include *all* resistances, such as those due to rolling friction, sliding friction, curves, wind, &c.; the latter two are seldom noticed in practice, so that if $r$, $r'$, &c., be their resistances, in the same unit as W, $R = r + r' + \&c.$

If $f$ be the co-efficient of friction for rolling loads, $f'$ the co-efficient of friction for sliding loads, and, if $W'$ be the weight of the carriages braked, the resistances are for trains

Unbraked, $R = r = W f$,

Braked throughout, $R = r' = W f'$,

Partially braked, $R = r + r' = (W - W')f + W'f'$,

For the last case, (equation 4) $s = \dfrac{W V^2}{30\left((W - W')f + W'f' \pm \frac{W}{n}\right)}$ .....(4*a*)

The sum of all retarding forces, including even gravity, &c., may be obtained in fractional terms of the unit of total weight of the train by dividing above and below by W, so that the denomination in equations (4, 4*a*),

$$\text{is } \frac{30 R \pm \frac{W}{n}}{W} = \frac{30\left((r + r' + \&c.) \pm \frac{1}{n}\right)}{W}$$

and equation 4*a* becomes,

$$s = \frac{V^2}{\frac{30\left((W - W')f + W'f' \pm \frac{1}{n}\right)}{W}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

This equation is the most useful in practice.

The following are examples worked by the preceding formulæ.

Data, $W = 158$ tons, $W' = 93$ tons, $V = 20$ miles per hour, $f = \frac{1}{12}$ of the weight.

*Example* 1. (Formula 4) $s = \dfrac{W V^2}{30 R} = \dfrac{W V^2}{30 W f'} = \dfrac{V^2}{30 f'}$

$$\therefore s = \frac{400 \times 12}{30} = 160 \text{ feet.}$$

*Example* 2. A train ran away down the Bhôre Ghât incline of 1 in 37. Total weight of train $W = 158$ tons; weight of train braked $W' = 93$ tons.

If co-efficient of rolling friction, $f = \frac{1}{12}$; of sliding fric-

tion $f' = \frac{1}{280}$; $n = 37$; in what distance ought it to have been stopped* had the brakes been properly applied?

*Formula* 5. $$s = \frac{V^2}{30\left\{\frac{(W - W')f + W'f'}{W} - \frac{1}{37}\right\}} =$$

$$\frac{400}{30\left(\frac{\frac{65}{280} + \frac{93}{12}}{158} - \cdot027\right)} = \frac{40}{3 \times \left(\frac{7\ 982}{158} - \cdot027\right)}$$

$$s = \frac{40}{3 \times \cdot0235} = 567 \text{ feet, nearly.}$$

The *time*, in seconds, required by a train having an initial velocity V (feet per second) to pass over a space $s$ (in feet) is

$$t = \frac{2\,s}{V} \text{ or } \frac{Wv}{32\ 2\ R} \quad \text{.........................(6)}$$

For V in miles per hour—

$$t = \frac{s}{0\ 734\ V} \quad \text{.................................(7)}$$

The retardation of friction is frequently expressed in pounds per ton.

If $p$ = the resistance in pounds per ton of the weight, W, causing friction; $p'$ of the weight W'; and so on—

$$p = 2240\,f \qquad p' = 2240\,f, \text{ \&c.};$$

$$\text{or, } R_1 \text{ (in pounds)} = W_1 \text{ (in tons)} \times p + W'\,p' + \text{\&c.},$$

$$\text{and, } R_1 \text{ (in tons)} = \frac{W_1 \text{ (in tons)} \times p + W'\,p' + \text{\&c.}}{2240}$$

and equation (4) becomes, for weights and resistances in tons,

$$s = \frac{2240\ W\ V^2}{30\left\{(W - W')\,p + W'\,p' + \text{\&c.}, \pm \frac{W\ 2240}{n}\right\}} \quad \text{.........(8)}$$

and, in a form corresponding to equation (5)

$$s = \frac{74\cdot8\ V^2}{\frac{(W - W')\,p + W'\,p'}{W} \pm \frac{224}{n}} \quad \text{.....................(9)}$$

The previous examples, 1 and 2, worked by these formulæ are:—

When $p' = \frac{2240}{12} = 186\cdot7$ lbs. per ton; $p = \frac{2240}{280} = 8$ lbs. per ton.

*Example* 1: $$s = \frac{74\cdot8\ V^2}{\frac{W\ p'}{W}} = \frac{74\ 8 \times 400}{186\cdot7} = 160 \text{ feet.}$$

*Example* 2: $$s = \frac{74\cdot8\ V^2}{\frac{(W - W')\,p + W'\,p'}{W} - \frac{2240}{n}} = \frac{29920}{\frac{6\cdot5 \times 8 + 93 \times 186\cdot7}{158} - 60\ 5}$$

$= 567$ feet.

* This example is taken from the Report of the Bhôre Ghât Accident Commissioners.

In any of these equations, if we suppose the resistance equal to the total weight, we have the space passed through by the train exactly that of a body projected vertically upwards; or, what is the same thing, equal to the height due to the velocity. This height may be obtained from one of the many tables of heights and velocities, and if we increase this height in the inverse ratio of actual resistance to the total weight (*i. e.*, multiply by $\frac{W}{R}$) we obtain the actual space passed through.

For instance, in the last example, the resistance for each ton of weight is $113 \cdot 2 - 60 \cdot 5 = 52 \cdot 7 \therefore \frac{W}{R} = \frac{2240}{52 \cdot 7} = 42 \cdot 5$; and the theoretical height required to produce a velocity of 20 miles an hour, (= 29·3 feet per second,) by tables of heights and velocities, is 13·34 nearly $\therefore S = 29 \cdot 3 \times 13 \cdot 4 = 569$, nearly. On this principle the following table enlarged from "*Engineering*"* is founded.

TABLE OF SPACES passed over by trains, for given velocities and resistances; also showing Time occupied in passing over such spaces.

| SPEED OF TRAIN. | | HYPOTHETICAL CASE. | | ROLLING FRICTION. | | | | SLIDING FRICTION. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Resistance equal total weight, or 2240 lbs. per ton | | Resistance equal $\frac{1}{224}$ weight, or 10 lbs. per ton. | | Resistance equal $\frac{1}{320}$ weight, or 7 lbs. per ton. | | Resistance equal $\frac{1}{10}$ weight, or 224 lbs. per ton. | | Resistance equal $\frac{1}{7}$ weight, or 320 lbs per ton. | | Resistance equal $\frac{1}{5}$ weight, or 448 lbs per ton. | |
| Miles per hour. | Feet per second. | Distance. | Time | Distance. | Time. | Distance | Time. | Distance. | Time | Distance | Time. | Distance. | Time. |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | | Feet. | Sec. | Feet. | M. S. | Feet. | M. S. | Feet. | Sec. | Feet. | Sec. | Feet. | Sec. |
| 60 | 88·00 | 120 25 | 2·73 | 38480·0 | 1–27·4 | 26936·0 | 10–12 | 1202·5 | 27·3 | 841·75 | 19 1 | 601·7 | 13·7 |
| 55 | 80·67 | 101 12 | 2·50 | 32358·4 | 1–20 | 22650·8 | 9–21 | 1011·2 | 25·0 | 707·84 | 17·5 | 505 6 | 12·5 |
| 50 | 73·33 | 83·60 | 2 28 | 26752·0 | 1–13 | 18726 4 | 8–30 | 836·0 | 22·8 | 585 2 | 15·9 | 418·0 | 11·4 |
| 45 | 66·00 | 67·64 | 2·04 | 21632·0 | 1–5 | 15142·4 | 7–39 | 676 0 | 20 4 | 473 5 | 14·3 | 338 0 | 10·2 |
| 40 | 58·67 | 53·50 | 1·82 | 17120·0 | 0–58·2 | 11984·0 | 6–48 | 535·0 | 18·2 | 374·5 | 12·7 | 267 5 | 9·1 |
| 35 | 51·33 | 40·86 | 1·59 | 13075·2 | 0–50·9 | 9152·6 | 5–57 | 408 6 | 15·9 | 286·0 | 11·1 | 204 3 | 7·9 |
| 30 | 44·00 | 30·06 | 1·36 | 9619 2 | 0–43·5 | 6733·4 | 5–6 | 300·6 | 13·7 | 210·4 | 9.5 | 150·3 | 6·8 |
| 25 | 36·67 | 20·90 | 1·13 | 6688·0 | 0–36·2 | 4681·6 | 4–15 | 209·0 | 11 4 | 146·3 | 7·9 | 104·5 | 5·7 |
| 20 | 29·33 | 13·34 | 0·91 | 4256·0 | 0–28·8 | 2979 2 | 3–24 | 133·0 | 9·1 | 93·1 | 6·3 | 66·5 | 4·5 |
| 15 | 22·00 | 7·51 | 0·68 | 2400·0 | 0–22·1 | 1680·0 | 2–33 | 75·0 | 6·8 | 52·6 | 4·7 | 37·5 | 3·4 |
| 10 | 14·67 | 3·35 | 0 45 | 1072·0 | 0–14·4 | 750·0 | 1–42 | 33·5 | 4·5 | 23 4 | 3·1 | 16·7 | 2·3 |
| 5 | 7·33 | 0·83 | 0·22 | 255·6 | 0–74 | 186·0 | 0–51 | 8·3 | 2·2 | 5·8 | 1·5 | 4·1 | 1·1 |

* 18th February, 1870.

In this Table, column 3 is calculated by formula, $s = \frac{v^2}{2g} = \frac{v^2}{64 \cdot 4}$ ; and columns 5, 7, 9, 11, 13 by formula, $s = \frac{v^2}{64 \cdot 4 f}$, in which $f = \frac{1}{320}, \frac{1}{224}, \frac{1}{10}, \frac{1}{7}, \frac{1}{5}$, respectively.

*Use of Table.*—To find the distance a train will travel after the application of the brakes.

Calculate the Algebraic sum of all the resistances acting on the motion of the train; divide the total height of the train by this sum and multiply the quotient by the tabular number in column 3, corresponding to the speed of the train.

*Example* 3.—Suppose a train moving 55 miles an hour, and the resistance of brakes, &c., is one-fifth the weight; in what distance will it stop?

By table for speed = 55 miles in column 3, the distance (supposing resistance equal the weight) = 101·12, and $101 \cdot 12 \times \frac{W}{\frac{1}{5} W} = 101 \cdot 12 \times 5 = 505 \cdot 6$ feet (*see* also column 13). This is the minumum distance, and supposes the brakes to have been applied instantaneously at a given signal; such is, however, practically impossible; but we may approximate to the time lost in applying them thus :—

*Example* 4.—Suppose speed and resistance, as in previous example, and that we have found the train has taken 1,000 feet to stop in; what *time* has been lost in applying the brakes?

$$100 - 505 \cdot 6 = 494 \cdot 4 \text{ feet must have been run without brakes,}$$

$$\text{and } \frac{494 \cdot 4}{80 \cdot 7} = 6 \cdot 12 \text{ seconds is the time lost.}$$

In comparing the Value of Brakes, we may thus approximate to the speed of application, and also obtain a general "figure of merit;" but as the retarding action of brakes is a gradually increasing resistance till they are fully applied, it will be necessary, in order to obtain accurate results, to have a reliable speed indicator fitted to the train; and then, when the brakes are fairly in action, to note the speed at a given point and the distance run before the train stops. This distance, divided by the distance which would have been run had the resistance equalled the weight, gives the co-efficient of friction of the brake, and this quotient may be taken as an accurate "figure of merit." The above process eliminates inaccuracy due to time lost in applying the brakes, and shows their efficiency when on. Of course, the lower the figure of merit, the better the brake.

A combination of this and the former mode of observation will show (assuming there is no mistake on the part of the person entrusted with the management of the brake) the merit of the arrangement by which the brake is applied.

The values of the co-efficient $f$, $f'$ and $p$, $p'$ vary within considerable limits, and depend on the varying circumstances of each case, roughly speaking.

Rolling friction:
- in ratio to total weight $= f$, varies from $\frac{1}{280} =$ ·0036 to $\frac{1}{217} =$ ·0046
- in pounds per ton $= p$, varies from 8 to 10 lbs.

Sliding friction:
- in ratio to weight on braked wheels $= f'$, varies from $\frac{1}{4} =$ ·25 to $\frac{1}{7} =$ ·14
- in pounds per ton $= p'$, varies from 560 to 320 lbs.

Strictly speaking, the former co-efficients, $f$ and $p$, vary with the velocity according to formulæ given, by Clark, Russel, &c.,* (*see* also table, *ante*).

The latter co-efficients are also considered by M. Rochet, to diminish with the speed according to a formula which he has published.—

$$f' = \frac{f'' + \gamma a V}{1 + a V}$$

in which

$f''$, for any surfaces $=$ 0·3, 0·25, 0·2; for damp surfaces $=$ 0·14.

$a$, for wheels sliding on rails $=$ ·03; for skids sliding on rails $=$ 0·07.

$\gamma$, not determined, but mean while to be taken as inappreciably small.

From experiments recently made by Captain White, R.E., on the

* $f = \cdot 00268 \left(1 + \frac{V - 10}{20}\right)$

$p = 2240 f$

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| V = | 10 | 15 | 20 | 30 | 40 | 50 | 60 | miles per hour. |
| $f$ = | ·00268 | ·00335 | ·00402 | ·00536 | ·0067 | ·00804 | ·00938 | co-efficient of friction. |
| $p$ = | 6 | 7·5 | 9 | 12 | 15 | 18 | 21 | lbs. per ton. |

Rankine's "Civil Engineering," Art. 429, page 633

Bhôre Ghât incline, G.I.P.R. (Professional Papers, No. CCLXXIX.), it appears that the co-efficients of friction have the following values:—

For Dry rails from $\frac{1}{7}$ to $\frac{1}{15}$ averaging $\frac{1}{11}$.
For Damp rails „ $\frac{1}{14}$ to $\frac{1}{24}$
For Oiled rails „ $\frac{1}{15}$ to $\frac{1}{35}$
For Sanded rails „ $\frac{1}{9}$ to $\frac{1}{15}$
For Steel rails „ $\frac{1}{13}$ to $\frac{1}{17}$

It appeared to Captain White that the co-efficient for a *Dewy* rail should be taken at $\frac{1}{30}$, and he arrived at the conclusion, (a curious one,) that the co-efficient of adhesion of an ascending locomotive was greater than the co-efficient of friction of a descending one.

J. H. E. H.

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# No. CCXCII.

## IRRAWADDY DELTA SURVEY.

*Report of Operations during* 1869. BY LIEUTENANT-COLONEL J. F. STODDARD

IN my first report, submitted in the month of June, I described the operations of the survey party from the commencement of the field work until the setting in of the rainy season. In this my *final* report, I will state the nature of the work performed since then and up to the present time.

This consisted in:—

(*a*). Plotting the field work of the last hot season.

(*b*). Observing and registering the several gauge rods set up at various points on the river.

(*c*). Taking sections of the river at one or more places, and

(*d*). Measuring velocities of the chief section (Prome) for some days before and after the recent high flood, in order to obtain the true flood discharge of the Irrawaddy, especially when at its highest level.

Accompanying this report are the Sheets* showing the levels and survey taken in April and May. Sheets I. to IV. inclusive contain the levels and survey along the left bank of the river from Prome to Syminine, a distance of 50 miles, being partly on the line A A, and partly on the line C C of the sketch map which accompanied the Chief Engineer's memorandum of instructions, dated 22nd February last. Sheets V. and VI. contain the levels and survey from Syminine to Poungday, a distance of 20 miles, on the line I I of the sketch map: and Sheets VII. to IX. inclusive show the

* Only the Index Map has been here printed.—[ED.]

levels along the trunk road from the junction of the old and new roads, 4½ miles below Prome to Poungday. These last being only "check levels," taken by Mr. Bell late in the season, no proper survey was attempted, but the direction of the line only has been plotted from the bearings; levels were also taken along line B B of the sketch map from Prome to Engmah bridge, and along A A from the bridge to Mengdoo, by Mr. Mackay, but these have not been plotted for reasons stated in my former report.

It will be seen from the sections that the flood of 1868 (supposed to have been one of the highest ever known) began to top the banks of the river in the Delta at Kyoma, 10 miles above Syminine, and that its average depth on the ground thence to Syminine was about 4½ feet. On the cross section from Syminine to Tahpoon, owing to the fall of the ground towards the Hline on both sides, the depth of flood water was rather more, averaging about 5 feet. It also appears from the sections that the ground falls from the Irrawaddy to the Hline 3¼ feet in 5 miles, and from Tahpoon to the Hline 6½ feet in the same distance, the slope in the latter case being just double that of the former.

Five gauge roads were established at the following stations in May last, namely at Prome, Myanoung, Shoay-gyeen, Noukmee, and Henzadah (or rather a little below Henzadah or Oukyuagalay). These gauges were observed and registered once a day by one or other of the subordinates of the Department, whose duties lay in the neighbourhood. Mr. Gordon at Henzadah rendered me the greatest help in this matter, as four out of the five gauges were in his division, and, with one or two exceptions, the registers seem to have been kept always pretty accurately, judging from the general uniformity of the curves as plotted on Sheet X. which accompanies this report. Mr. Gordon's gauges were all set up by the 1st of May, but as the Prome gauge was not ready till the 11th of that month, I started with low-water of that date as zero for all five gauges, in plotting the curves, so that the diagram gives a true representation (so far as the registers may be relied on) of the *comparative extent* of each oscillation in the surface of the river at the five gauge stations. From the diagram it is apparent that there were 7 distinct oscillations between the 11th of May and the 26th of August: the *first* occurred between the 11th and 16th of May; the second between the 26th of May and the 1st June; the third between the 2nd and 10th of June; the *fourth* between the 11th and 23rd of June; the *fifth* between the 24th of June and the 5th July; the *sixth* be-

tween the 6th and 26th of July; and the *seventh* between the 3rd and 26th of August.

The height of each rise measured from the *foot* to the *top* is shown below for the five stations :—

*First Oscillation.*

| | | | | |
|---|---|---|---|---|
| Prome | 3 | feet | 1 | inch. |
| Myanoung | 1 | ,, | 1 | ,, ? |
| Shoay-gyeen | 3 | ,, | 5 | ,, |
| Noukmee | 2 | ,, | 5 | ,, |
| Henzadah | 4 | ,, | 0 | ,, |

*Second Oscillation.*

| | | | | |
|---|---|---|---|---|
| Prome | 4 | feet | 4 | inches. |
| Myanoung | 1 | ,, | 8 | ,, ? |
| Shoay-gyeen | 5 | ,, | 0 | ,, |
| Noukmee | 3 | ,, | 10 | ,, |
| Henzadah | 4 | ,, | 3 | ,, |

*Third Oscillation.*

| | | | | |
|---|---|---|---|---|
| Prome | 2 | feet | 8 | inches. |
| Myanoung | 2 | ,, | 3 | ,, |
| Shoay-gyeen | 3 | ,, | 1 | ,, |
| Noukmee | 2 | ,, | 11 | ,, |
| Henzadah | 2 | ,, | 9 | ,, |

*Fourth Oscillation.*

| | | | | |
|---|---|---|---|---|
| Prome | 7 | feet | 8 | inches. |
| Myanoung | 7 | ,, | 9 | ,, |
| Shoay-gyeen | 8 | ,, | 7 | ,, |
| Noukmee | 8 | ,, | 0 | ,, |
| Henzadah | 7 | ,, | 1 | ,, |

*Fifth Oscillation.*

| | | | | |
|---|---|---|---|---|
| Prome | 4 | feet | 8 | inches ? |
| Myanoung | 6 | ,, | 0 | ,, |
| Shoay-gyeen | 6 | ,, | 4 | ,, |
| Noukmee | 5 | ,, | 9 | ,, |
| Henzadah | 5 | ,, | 9 | ,, |

*Sixth Oscillation.*

| | | | | |
|---|---|---|---|---|
| Prome | 9 | feet | 10 | inches. |
| Myanoung | 8 | ,, | 7 | ,, |
| Shoay-gyeen | 8 | ,, | 0 | ,, |
| Noukmee | 7 | ,, | 1 | ,, |
| Henzadah | 6 | ,, | 8 | ,, |

*Seventh Oscillation.*

| | | | | |
|---|---|---|---|---|
| Prome | 10 | feet | 8 | inches. |
| Myanoung | 9 | ,, | 6 | ,, |
| Shoay-gyeen | 8 | ,, | 0 | ,, |
| Noukmee | 6 | ,, | 8 | ,, |
| Henzadah | 6 | ,, | 3 | ,, |

Discarding the rises marked as *doubtful* in the above statement, and which are evidently erroneous (as a mere inspection of the diagram proves) the rise seems to be nearly the same at all five gauge stations; at least it is so for the first *five* oscillations; the difference between the *maximum and minimum* rises averaging about 33 per cent. only. For the last two oscillations the difference is more marked; the *highest* rise in these instances being at Prome, (where the river is confined within high banks) and the *ratio* which the rises at Prome bear to those at Henzadah (the lowest in the scale) becoming 1·5 and 1·7 to 1 respectively, as is to be expected, owing in part to the increasing discharge of the Thambyadine and Nawoon creeks above Henzadah, but chiefly no doubt to the greater amount of "spill" water which overflows the banks East and West from the Irrawaddy.

Cross sections of the river were taken at Prome, Myanoung and a few miles below Thayetmyo. They are plotted on Sheets XI, XII, and XIII. accompanying this report.* The method adopted in taking these sections was, I believe, that usually followed for large and rapid rivers, and is as follows:—

A straight reach of the river having been selected where the whole discharge of the stream is confined to one well defined channel, a base line of 1000 feet was marked out on the shore, close to the water edge, and therefore *parallel* to the direction of the stream; two conspicuous marks were set up, at each end of this base, which I shall call A, B, (A being the *upper* end). A line across the river and at *right angles* to the base was then projected by means of a Theodolite at B, and 2 or 3 poles with flags were set up in this *alignment* on both banks of the river. These marks were essential in order that the "soundings" might be confined to the correct line of cross section required. Provided with a good "box sextant" and a 100 feet line with a 14 lbs. "deep-sea-lead" at the end of it, operations were begun at one bank and gradually carried across to the other, no opportunity of taking a sounding being lost when the boat was on the alignment as indicated by the flags on shore. One of my assistants took the sounding while I observed the angle subtended at that particular spot by the base line A B. Another assistant then entered both the sounding and the observed angle in a book. This operation being repeated as often as was considered necessary, a full and correct table of data was obtained from which the section of the river was afterwards plotted. As the greatest accuracy was needed in taking the Prome section, upwards of 200 soundings were taken here. Care was always taken to note down the reading of the gauge when soundings were going to be taken, in order that due allowance might be made in plotting the section for any variations in the height of the river between successive soundings.

When the river happened to be very wide, as at Myanoung, where a low sand bank divides the stream into two portions at low water, a second base line *parallel* to the first, and starting from the original alignment across the river, was marked out on the intermediate sand bank and the angles taken from it. Levels across the sand bank from water's edge to water's edge were also taken to complete the section. In plotting the sections for Prome and Myanoung, the distances of the soundings from the base

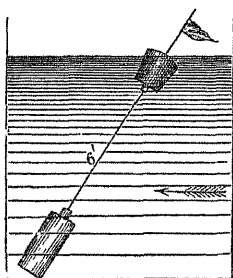
* One only is here given.—[ED.]

line were calculated by trigonometry, and thus much greater accuracy secured than would have been possible had the angles been plotted with a "protractor," as they became very small as the distance from the base line became greater. I may here state, once for all, that all *reduced* levels given either in this report or on the sections accompanying it, are with reference to the bench-mark on the obelisk at Prome, which, as stated in my first report, was *assumed* as 200 feet above high water springs. It is very desirable that this bench-mark should be verified by levels brought up from tidal water, and all reduced levels corrected accordingly.

The section of the river at Prome having been taken in the manner above described, the next thing which engaged my attention was to measure the velocity of the current in order to ascertain the discharge at various heights of the flood, especially when it reached that particular height when the river banks in the Delta below began to be overtopped, and also when the flood attained its *maximum* height. Observations were commenced at the Prome section (opposite to the Circuit house) on the 2nd of August and continued daily with scarcely any intermission (Sundays excepted) till the 2nd of September. The date on which the flood attained its highest level was the 25th of August, so that the velocity observations were made both when the flood was rising as well as when it was subsiding. The following was the method adopted in making the velocity measurements.

A base line of 200 feet was accurately chained and pegged out at right angles to the line of cross section already sounded and which latter cut the velocity base in the *centre* and perpendicularly. A theodolite was set up precisely over the peg at each end of the base, which I shall call A B (A being the *upper* end). I took the instrument at A, and one of my assistants (Sub-overseer Sheer Mahomed) took the one at B, while Mr. Bell took the time (a very important duty) by the seconds hand of a watch. The Theodolites being levelled and adjusted to Zero, and the telescopic axis of each on the Plummet of the other, the lower plates were firmly clamped and the upper were unloosed and turned round 90°, so that the distance between the central axes of the two telescopes (prolonged) was everywhere just 200 feet apart, while they cut the direction of the stream perpendicularly. In this position, the upper plates were again clamped. All being ready on shore, an intelligent native was sent in a small boat with some 50 floats (to be presently described) with instructions to distribute them as equally as possible across the river, and at

some distance above the line of sight of the observer at A, in order that the floats might have acquired the true velocity of the current before they crossed the upper end of the velocity base. Another small boat was sent below the line of sight of the observer at B, to pick up the floats which were too valuable to be lost. On a signal made on shore, the man in the boat above dropped a float. The observer at A gave warning when it approached his line of vision, in order that the assistant with the watch might be prepared to commence counting the seconds directly the float crossed the centre of the cross wires of the theodolite at A, of which the observer then gave instant notice, till it crossed the wires of the theodolite at B, which was also instantly notified by the assistant there. Observer A, as soon as the float passed him, unclamped the upper plate of his theodolite and followed the course of the float with his telescope till its passage across the wires of telescope B had been announced, when he read off the "angle" and bringing his telescope back to its original position, reclamped it for another observation. The Assistant with the watch entered in a book, the "angle" observed, and the number of seconds the float took in passing over the 200 feet. I should not omit to mention that at the commencement and close of each day's work, the height of the river as indicated by the gauge rod was carefully noted, and the mean of the readings (if there was any difference) recorded.

"*Double floats*" were always used, excepting when the depth of water over the sand bank at the West end of the section was too little, in which case single floats were used; the *lower* float was of what is known as "iron-wood," the specific gravity of which being found to be *very little* more than that of water charged with silt, rendered it well suited for the purpose, as it moved forward with the current just as the water it displaced would have done. The upper float was of "teak-wood," and made just of sufficient size to keep the lower float from sinking to the bottom, without rising too much above the surface of the water itself and be thereby rendered liable to the retarding or accelerating influence of every *up* or *down* stream breeze. The two floats were connected by a thin cord 6 feet long, experiment having shown that the maximum velocity was at that depth below the surface when the wind

was *up* stream and not too strong. This was nearly always the case during the observations. There were some *calm* days, but never one when the wind blew *down*-stream. Adopting the scale used on the Mississippi river for classifying the force of the wind, namely 0 for a perfect calm, and 10 for a gale, I should say force No. 2 or perhaps No. 3 was the greatest we ever had. The above sketch will perhaps show the kind of float used better than the above description. A small flag of some color, easily discernible at a great distance, was fixed on the top of the upper float. That the *stronger* current was *below* the surface was proved by the appearance of the upper float and the flag, which invariably appeared as shown in the sketch; and if further proof of this fact were wanted, we find it in the practice so common with the Burmese boatmen of using what is very happily called a "water sail" in descending the river.

A single day's observations sufficed to show that the velocities varied in a very marked degree at certain angles, as observed by the theodolite A. It was therefore considered advisable to *group* the velocities comprised between these angles into separate divisions; and as it was found that there were at least 8 distinct changes in the velocities from bank to bank, a table was drawn up in which the velocities are tabulated in 8 divisions or columns, and the cross section of the river, was also divided into a similar number of divisions, which I have called A, B, C, D, E, F, G and H: A being the shore divisions farthest from, and H that nearest to, the base line A B. This "tabular statement," accompanying this report needs a word of explanation.

It will be observed that it is divided *horizontally* into 12 compartments, one for every foot of rise of the river as shown by the Prome gauge. The uppermost compartment contains the velocities, &c., &c., for the height 183 to 184, and the lowest compartment for the height 194 to 195 above H. W. The statement is also divided *vertically* into several columns, in which are entered (beginning on the left), 1st, The *dates* of observation; 2nd, The "gauge reading" reduced to H. W. level; 3rd, The *area* of the several divisions of the river section for each gauge reading; 4th, The *total area* of the whole river section; 5th, In eight double columns are shown the *times* in seconds in which the floats passed over 200 feet, arranged in *groups* according to the angle shown at the top of each column; the second column gives the *mean times* for each group; 6th, In eight more columns are shown the *mean velocities* in feet per second for

the several divisions, and which were thus found: The *distance* traversed by the floats, namely 200 feet, was divided by the *mean times* and the quotient multiplied by some known "co-efficient." For the two shore divisions Prony's co-efficient ·8 was used, because it was seldom practicable to observe a float close in shore, and therefore the mean times for these divisions as given in the table, must be considered too little. For the remaining divisions, the co-efficient used was ·93, which was the one used in the Mississippi survey, giving apparently the truest results; 7th, In eight more columns are entered the discharges of the several divisions, which are, of course, found by multiplying the *areas* given in the 4th column of the table by the appropriate *mean velocities*; 8th, In the next column is given the *total* discharge of the river, which is found by adding together all the partial discharges above-mentioned; 9th, This total discharge is next divided by the area of the whole section as given in the 5th column of the table, and the quotient, which is the true mean velocity of the river from bank to bank, is entered in its proper column; 10th, The mean velocity in *miles per hour* is given in the last column but one; and 11th, The discharge as calculated by the Mississppi formulæ (to be hereafter mentioned) is entered in the last column of the table.

It is to be here remarked that whenever, from a deficiency of the observations in any of the divisions, or whenever, from a total absence of observations for any particular stand of the river, it was not possible to get the *mean times* by actual experiment, they have been *interpolated*, which the tabular form of the statement renders an easy process. For the very high stands of the river this was fortunately not necessary, as a considerable number of observations were made at those periods. It remains to explain, with reference to the table, that when the observations were made when the river was *rising*, the entries are all made in *black* figures*; and when the river was *falling*, in *red*†. The necessity for observing this distinction is apparent from the table, from which it will be seen that for the same stand of the river as indicated by the gauge, there was a marked *diminution* of "velocity," and consequently of discharge, when the river was *falling*. This is of course owing to a decrease in the slope or hydraulic inclination of the surface, since no sensible change had taken place in the area or perimeter or depth of the section.

* The red figures are shown in the table in Italics.

It will be perceived from the table that the highest velocities are always in division D, or between the angles 263° and 265°, but this is *not* the division in which the greatest depth is. In the section the maximum depth is in division C. This anomalous fact can, I think, be explained thus:—During the flood season, the surface of the water is nearly covered with "whirls" and "boils" which shoot upwards from the bottom and spread out on reaching the top: these whirls and boils are more numerous and much larger and stronger in the deepest part of the stream, owing to some configuration of the bed or deflections of currents, and their *retarding* action on the floats and the velocities must, therefore, be greater than in any of the other divisions. Probably at *low water*, the greatest velocity will be found in the deepest part.

Having found the discharge of the river at various heights of the late flood by *actual measurement*, I next attempted to calculate it by one or other of the usual formulæ. To do this, it was requisite to ascertain the "slope" or "hydraulic inclination" of the surface of the river at the place where the velocities were observed, since this is one of the two indispensable quantities, the "hydraulic mean depth" or "mean radius" or being the other. The latter is obtained immediately from the cross section, but it is not so easy to find the former in times of flood, as the surface of the water then is not a uniform even plane, but a very uneven and convex surface, the convexity increasing from the banks till the strongest current is reached, where it is at its maximum. This convexity is sometimes so great that it can be detected by a practised eye. The attempt was however made, when the flood had been steadily standing at its highest level; the day was calm and therefore favorable for such a delicate operation. Two permanent bench-marks were made at 2,240 feet apart, and at equal distances on either side of the centre of the velocity base, and the difference of level between them accurately ascertained by a good "spirit level." The levels were taken with great care three times, and the mean of the three results taken. The difference of level between the water surface and the bench-marks was then taken at the same time with the utmost accuracy. The slope was then found to be ·00004687, which gives very nearly 3 inches a mile. With this "slope" and the known "mean radius," the *velocity* and *discharge* were computed by Du Buat's celebrated formula, by Eytelwein's and by Mr. Nevill's *new* formula; but all (even the last one) gave results far short of the truth, so that none of these formulæ are adapted for such very large

rivers as the Irrawaddy. I then computed the "velocity" and "discharge" by the formula given in the celebrated Mississippi Report and found that it gave results, varying, by a *very small percentage only*, from the measured quantities. The discharge of the Irrawaddy at Prome on the 25th August was found by actual measurement to be 1,312,750 *cubic feet a second*, and computed by the Mississippi formula it is 1,300,900 cubic feet; the former quantity exceeds the latter by *less than one per cent.* Having found a formula which gives results differing so little from the truth, it was now easy to compute the discharge of the river at the highest flood ever known, namely, that of last year, which is said to have reached the level of 196·23, or *nearly* 2 *feet higher* than the highest flood of the present year. The only point on which information was wanting was the "*slope*" or "hydraulic inclination" and this must be assumed. The slope was most probably rather more than it was at the time of highest discharge this year, which was not quite 3 inches a mile, as above stated.

Assuming that it was as much as 3½ inches a mile in 1868, the discharge computed by the formulæ was 1,424,000 cubic feet a second; increasing this quantity by about 2 per cent. it becomes 1,450,000 cubic feet; and I should say this is rather over than under the truth—it is, however, safer to assume the "discharge" *too high*, than *too little*, and in future calculations I shall assume it to have been 1,450,000 cubic feet per second. It was also very important to ascertain the discharge when the river was at that particular height when the banks below from Myanoung* downwards began to be overtopped. I therefore requested Mr. Wallnutt, the Assistant Engineer at Myanoung, to telegraph to me as soon as the flood reached a certain point on the gauge there, and which I knew from the levels taken in April last was the level of the bank at Syminine. On the morning of the 22nd July I received a telegram, when the river was standing at 191·5, that it had reached the point indicated, at 11 P. M. of the 21st July. The water must have reached the top of the banks at Syminine when the gauge reading at Prome was about 191·416. The discharge of the river was then found by actual experiment to be 1,182,920 cubic feet, and by the formulæ I computed it at 1,181,820† cubic feet per second—the observed exceeding the computed discharge by less than 1-10*th per cent.* In future calculations I shall take the mean of these quantities, or 1,182,000 cubic feet, as the true discharge

* Or rather Kyoma, 10 miles above Myanoung. † *See* table on the Prome Section.

when the banks below begin to be overtopped. On the section I have given the formula by which the computations were made, and all the data for calculating the *velocity* and *discharge* for the three stands of the river, namely, 191·416 when it begins to submerge the banks below; 194·416 when the maximum height of the present year was reached; and 196·23 the greatest height of flood (1868) ever known.

Having ascertained with sufficient, if not perfect accuracy, the greatest flood discharge ever known, and also the quantity of water which the channel of the river is capable of conveying without rising over its banks, I now approach the main question, the true object in fact of all these investigations, namely, "what is the best means of protecting the delta lands below from the flood?" Before I discuss this point, however, I must express my regret that I have not had a little longer acquaintance with the Irrawaddy river and the delta itself. I should then have had more data to support the views (which, from the short time I have had to study the subject, I have been compelled to entertain) as to the best measures to be applied for preventing the floods from doing the injury which they now do to the rich lands of the delta on the East side of the river. Had I remained till the end of November or December, it was my intention—1st, To take several accurate sections of the Irrawaddy both at the gauge stations and others; 2nd, To ascertain by means of a spirit level the slope in the surface of the water at those places before the flood marks were obliterated; 3rd, To examine the Hline river lower down than Mengdoo, especially from Beeling downwards; and 4th, To run a line of levels up from tide water to one or other of our bench-marks at Poungday or Syminine. I think, however, that even with such meagre data as I now possess, I shall be able to advance some definite and practicable scheme for protecting the land below from the effects of inundation.

I have kept in view the four points mentioned in the 2nd para. of the Chief Engineer's memo. of instructions to me of the 22nd February, 1869, and my proposals will be found in no particular opposed to those views, excepting on one point, and that the *distance* of the embankment (which it is proposed to throw up along the whole front of the river on the Eastern side) from the edge of the river. In the large map submitted to the Government of India with the Chief Engineer's letter of the 23rd

June, 1868, I observe that it is proposed to place this embankment *fully a mile* from the river. From my experience in the Godavery where the embankments on *both* sides are not more on the average than 200 or 300 feet from the river, I am of opinion that no danger is to be apprehended on the Irrawaddy by placing them at the same distance. There are points on the river, doubtless, where it would be prudent to place the embankment further back from the river owing to "sets" of the current and consequent *erosion* of the banks, but for this there is a remedy, as I hope to show before I close this report. I consider that the Irrawaddy is a much easier river to deal with in this repect than the Godavery—1st, It rises very much more gently. I have known the Godavery to rise as many *feet*, as the Irrawaddy does *inches*, in 24 hours; 2nd, The latter river is not *dammed* across by a weir as the Godavery is, which tends to raise the level of the flood higher.

Moreover, by throwing the embankment so far back as one mile, or even ¼ of a mile, from the river, much valuable land, indeed it may be said truly the *most valuable* portion of the land (from the fact of the best and richest particles of silt having been deposited on it) will be left *outside* and at the mercy of the floods. This valuable strip of land will eventually, when the population is sufficiently increased and irrigation becomes a *necessity* (which it will surely do throughout the delta, perhaps not many years hence) be required for cultivation; and, *secondly*, owing to the rapid slope of the ground from the Irrawaddy towards the Hline, the embankment will be placed on *lower* ground; it must therefore be *raised higher* than if it had been constructed nearer the river. This will add to the expense, and will, besides, increase the danger of the embankment being breached, so that there is no advantage gained by constructing it so far from the river, unless it be that the greater width given to the river in time of high flood will keep down the level of the water, and so render a lower embankment sufficient; but this is a very doubtful advantage, as, against the saving in the first construction of the embankment, must be set the loss of revenue from such a considerable extent of the *best* land being left exposed to the floods.

In the Chief Engineer's memo. submitted to Government with his letter above-mentioned, it is proposed to cut some 3 or 4 channels from the Irrawaddy to the Hline in order to "assist the natural outlet of the former into the latter." With all respect for the Chief Engi-

neer's opinion, I must say that I think it would be a fatal mistake to allow any of the Irrawaddy water to enter the Hline, at any point between the head of the Delta at Kengyua to the Panlang creek at Nyandoon, at all events above the Segaghee creek. Firstly, the Hline is acknowledged on all hands, including the Chief Engineer himself, to be scarcely up to the mark of draining its own basin (*vide* para. 5 of Colonel Fraser's memo, already quoted, and Colonel Oliphant's memo. para. 27 which accompanies it). Colonel Oliphant has "hit the blot" when he states, "I consider the inundation to be entirely due to the Irrawaddy waters, but *mainly to the creeks which commence discharging into this basin in July*. The Hline *cannot* carry off the accumulated quantity of water brought in by these creeks, and so the height goes on rising until it attains its maximum, when the spill floods of the Irrawaddy take place in August and September or October." *Secondly*, it is also allowed, on all hands, that the Irrawaddy has every tendency to deposit sand and silt on its left bank, and in the Delta this seems to be quite the fact. Such being the state of the case, it is not difficult to foresee the fate of any *artificial* cuts from the Irrawaddy to the Hline, particularly when it is also considered that the Hline is barely able to discharge the drainage of its own basin, and that its bed is (as at Mengdoo for instance) 7 *feet higher than the low water level of the Irrawaddy*. The consequence will be (I might say *must* be) that the "outlets" or cuts will be choked up with sand in perhaps the very first fresh.

I am, therefore, of opinion that no matter what height it may be necessary to give the marginal embankment along the East bank, (and I hope to show that the extra rise in the surface of the water will be insignificant,) a *continuous* embankment *should* be made from Keng-yua as far as Nyandoon, a distance of 120 miles; and that no opening for Irrawaddy water to enter the Hline should be allowed higher up than the Segaghee creek. In this embankment, sluices will have to be provided, as has been done on the opposite side, for draining the lands into the Irrawaddy whenever its surface is low enough, but they should be *self-acting*, so as to exclude all the Irrawaddy water, while they let the drainage water pass out as quickly as possible. I could not help observing how difficult it must be to work the sluices in the river embankment at Myanoung, and it occurred to me then that the kind of sluice required was one which I had seen tried successfully in the Godavery; it is, I believe, the invention

of Colonel Horsely of the Engineers, and I am of opinion that it would answer admirably for *drainage* sluices. It is not expensive, (in fact in the long run much less so than wooden shutters,) it needs no men or machinery to lift or lower the valve, and it will last many years, if a coating of paint is applied to the iron shutter every year, and occasionally a little grease or oil to the hinges.

I have recommended above that all the creeks from Keng-yua to Nyandoon, or Segaghee creek, be permanently closed by the embankment. There is one creek, however, which seems from its importance to deserve a passing notice; I allude to that near Hteandeau. In the large map this is said to be used by boats in the flood season. If it should be considered on this account too valuable as a line of communication to be closed permanently, it might be locked at the head; but not being a *tidal* creek, a lock would not make it navigable all the year round, so that I would close it, and improve and, if necessary, lock the Segaghee creek instead. The latter is, I should imagine, within the influence of the tides, and if so, it would not be difficult to keep it open at all events for small boats throughout the year. This creek communicates with the Baulay river, and on this account perhaps, should not have a lock at the head, but be allowed to remain open as an *outlet* for flood waters of the Irrawaddy, which it would discharge into the Baulay river, without entering the Hline at all. It is, however, problematical whether from its proximity to tidal influences, it would be of much benefit to the Irrawaddy above as an outlet, and I would close it also permanently, and so make the Panlang creek the *first* and *only* line of water communication between the Irrawaddy and the Hline in the Delta.

Having incidentally alluded to the Panlang creek, I may here suggest that one or two steam dredges, similar to those in the Godavery at Cocanada, woulds oon effect great improvement in this valuable channel. It is silted up at its head near Nyandoon, and at one or two other places further down, which prevents its being used by steamers in the dry season. As a "detour" of 70 miles would be avoided in the passage of steamers, were the Panlang creek improved by dredging, I think it is well worthy of *immediate* attention, as delay will only make matters worse. Perhaps the Madras Government would be able to hand over one, if not two, of their large dredging machines, and they might be towed across the Bay in calm weather by one of the B. I. S. N. Co.'s steamers. Their com-

plement of mud barges should be sent also. The silt dredged out of the Panlang creek might be deposited on shore as embankments along the banks of the creek, or deposited in any of the loop channels, which would be an improvement, as at present these loop channels reduce the velocity of tide and encourage deposition of silt.

There is another point which I might notice here, in connection with the continuous marginal embankment I have recommended, by which the revenues of the *whole* Province would derive benefit, were all the creeks and "bayous" between the Irrawaddy and Hline closed permanently. I allude to the *wholesale* destruction of the young fish, which, to escape the strong currents of the river, take shelter in these creeks and swamps during floods. Directly the waters begin to fall, as I have witnessed over and over again, the whole population of the adjoining villages commence dragging with nets of the very smallest mesh, and so catch myriads of young fish, weighing perhaps a thousand or two to the pound, every one of which would in time have attained several pounds weight. This practice might be partially put down by legislation, but the easiest way would be to do away with the natural traps which are now entered by the fish, and where they find far less mercy than they would have had from the depredations of the large fry had they stayed in the river.

All extraneous supplies of water West of the Hline once cut off, there will be no necessity for embanking that stream on the West side whatever, and thus about 120 miles of very heavy and expensive embankments would be entirely dispensed with. It will not be then necessary to make the cross roads i, ii, iii, &c., in *embankment*. I presume it is intended that these roads are to be available for cart traffic, as well as for horsemen and pedestrians; if so, they must be at least 4 yards wide on top and *metalled.* Even if made 12 feet wide on top, I doubt very much if the carts will use the roads, as from their intended great height, and the natural timidity of the Burmese cattle, accidents will be numerous; and, consequently, the cartmen will again betake themselves to the natural surface of the ground, where there is no danger of upsetting. I would however *improve* the present roads and make new ones where there are none, but I would not *raise the roads more than is absolutely required to drain their surface efficiently.* The Hline is the natural catch drain of the country between the hills and the Irrawaddy, and everything should be done to improve its *draining* powers. From what I saw of it at Mengdoo it seemed to be overgrown

with grass and scrub jungle, and there are many shoal places in the bed caused, I have little doubt, by the very objectionable custom practiced by the natives of throwing fish weirs made of stakes, mats, and even earth across the channel. This practice cannot be too strictly prohibited, and the shoals should be cleared away and the scrub jungle eradicated gradually. Above all, none of the channels below, through which the flood-waters of the Hline now find vent into tidal water should be *closed.* I mention this because I see that the Chief Engineer in his memo. quoted above, proposes to close by an embankment the Baulay river. I have not seen this part of the Baulay, nor perhaps has Colonel Fraser done so, but looking at a survey and cross section of levels made in 1861 by Sub-Engineer Magrath, and which was lent me by the Commissioner of Pegu, it appears to me that the creek which it is proposed to close up is not the Baulay river, although it runs into it soon, but the Hline-Bouk, and according to Mr. Magrath's survey and levels, *a most important* outlet for the *Hline* waters, considering its *great* depth, and the *direction* from which the Hline proper enters it from above. The section shows that the Baulay river is 24 *feet deeper* than the *Hline* in the same parallel of latitude, and therefore it is to be presumed that of the two channels the Baulay is much more important as a vent for the Hline waters, than the Hline proper below the point of their bifurcation; and if such is really the case, it would not be advisable, if possible, to shut it up as proposed.

It is now time to revert to the question of how much the *extra* rise in the surface of the water below will be if the river is leveèd on the East side as it has been on the West. I have assumed the discharge of 1868 (the highest flood ever known) to have been as much as 1,450,000 cubic feet per second, to be on the safe side, and the discharge at *full* banks below at Myanoung has been found by observation and calculation to be 1,182,000 cubic feet per second. The difference, or 268,000 cubic feet is therefore the quantity which will be added to the river channel when confined between banks. As I have recommended that the leveè on the East side be thrown up at a distance of 200 or 300 feet from the river, I shall be on the safe side if I assume that the width of the river is *unaltered*, and that it is the same between leveès as it is at full banks; this also will greatly simplify the calculations. Having the section of the river at Myanoung it is easy to find the true mean velocity of the stream by

dividing 1,182,000 by 254,860 (the sectional area) which gives 4·64 feet *per second.* With this velocity, and the following formulæ, viz. :—

$Z = 0{\cdot}93\, v_{,} + 0{\cdot}072 \sqrt{v}$ ; and $S_{,} = \left\{ \frac{(p_{,} + W_{,}) Z)^2}{195\,.\,a} \right\}^2$ we obtain the slope or hydraulic inclination = ·00003448. The new slope $S''$ *after* the extra quantity of water is added to the above discharge (or $Q_{,,}$) could be readily computed, if the actual slope from Myanoung to tide water were known; but as this has not been ascertained yet by means of the spirit level, we may take the new slope to be the same as that just found, namely ·00003448, (or nearly 2·2 inches per mile,) and by doing this be on the safe side, as this is doubtless *less* than the true slope would be, and therefore we *decrease* the velocity, and *increase* the height of the flood in proportion. Let us now assume the total rise* ($x$) to be 5 feet. The new area of the cross section $A_{,,}$ now becomes 291,085 square feet (assuming, as I said before, that there was no alteration in the width $W_{,}$). The new "mean radius" $r_{,,}$ is now $\frac{291{,}085}{14615} = 19{\cdot}91$ feet.

With these values of $s_{,,}$ and $r_{,,}$ we find the new velocity $v_{,,}$ by the following formula :—

$$v_{,,} = \left\{ (225 \sqrt{s_{,,}} \times r_{,,})^{\frac{1}{4}} - 0{\cdot}0388 \right\}^2 = 4{\cdot}954 \textit{ feet per second.}$$

With this value of $v_{,,}$ we compute $x$ by the following formula :—

$x_{,} = \frac{Q_{,,} - a_{,} v_{,,}}{W_{1}\, v_{,,}}$, or, $\frac{1{,}450{,}000 - 1{,}262{,}576}{35{,}892} = 5{\cdot}22$ feet. As the true value of $x$ must be *intermediate* between 5·0, the value assumed, and 5·22, the value just computed, we shall be very near the mark if we take it as 5·111 or to be on the safe side again, at 5·25 feet. But the rise at Myanoung is *now* 4·25 feet, *so that the extra rise, after the river is confined between continuous "levels" on both banks, will not exceed one foot, and an embankment only* 8 *feet high will be* $2\frac{3}{4}$ *feet above the level of the highest flood at Myanoung.* The foregoing formulæ have been taken from the report on the Mississippi already mentioned; the degree of confidence they merit has been seen. They were severely tested in computing the oscillations caused by variation in discharge on that river for three different stations, and never varied more than 5 or 6 per cent. from the truth, (*see* Table at page 329 of the report,) and I believe the value of $x$, as above deduced for Myanoung, and everywhere else where the flood of 1868 did

* After the extra quantity of water is added to the discharge.

not lie deeper than 4¼ feet on the banks of the river, is *above*, rather than *below* the truth, and I believe so also, for the following reason :—

Above will be found a statement giving the height of seven oscillations of the river; of these, five took place while the river was still flowing *between banks* in the Delta throughout. Taking the *average* of these 5 oscillations, we get as the respective rises at the 5 gauge stations, viz., Prome, 4·483; Myanoung, 3 75; Shoay-gyeen, 5·283; Noukmee, 4·58; and Henzadah, 4·76 feet. The rise for Myanoung as before observed, is evidently too small. I shall take it as 4·483 instead, or the same as at Prome. Making the Prome rise *unity*, the following numbers give the *ratios* of the other stations, viz., Myanoung, 1 ; Shoay-gyeen, 1·18; Noukmee, 1·022; and Henzadah, 1·062. Multiplying the extra rise at Prome then from 191·416 (when it commenced to top the banks below) to 196·23 (the greatest flood ever known), or 4·814 feet, by the above ratios, we obtain as the rise of Myanoung, 4·814 ; for Shoay-gyeen, 5·68; for Noukmee, 4·92; and for Henzadah, 5·112 feet.* The above rise for Myanoung is *less* by 3 inches than the rise above computed, viz., 5·11 feet, so it is certain, I think, that we shall be prepared for any contingency if we assume the total rise at Myanoung, and elsewhere where the flood of 1868 rose to 4¼ feet above the banks, to be 5¼ feet. We cannot be far out in our calculations by taking only the oscillations when the river was below banks, as when the whole maximum discharge is confined between leveès the conditions will be almost the same.

I regret that I have not got sections of the river for the several gauge stations in order that the rise $x$ may be computed for them also, but from what has already been stated I think it may be taken as *certain that the extra rise caused by leveèing the river on both sides throughout the Delta, will not exceed the average of* 1 *foot.*

I alluded above to certain remedial measures for protecting the banks of the river from *erosion.* I shall therefore now endeavor briefly to describe the measures as practised very commonly in the Godavery, even

* *Note.*—Rejecting the 2 first oscillations, as the Myanoung gauge was evidently erroneously registered, and taking only the 3rd, 4th and 5th oscillations, we get the *average* rise at Prome = 5 feet, and at Myanoung 5·33 feet, being in the ratio of 1 to 1·066 Multiplying the rise from 191·416 to 196 23, or 4·814, by this ratio we get 5·13 *feet* as the *total* rise at Myanoung, and had we *assumed* the value of $x$ as 5·13 instead of 5 feet, we should have found by *computation* by the formulæ given in the text, that this was its *true* value. This remarkable agreement proves the accuracy of the formulæ as well as the deduction in the text that the *extra* rise *will not exceed one foot* when the leveès on both banks *are completed.*

where stone is so *plentiful*, on account of their comparative cheapness. In the Delta of the Irrawaddy where stone is a curiosity, or almost unknown, I think the plans which I am about to describe would be found to be most useful, the only materials required being grass and clay, a few bamboos and ropes—all of which are *abundant* in the Delta. The following rough sketches will explain what I have to say regarding the system of making "spurs" or groynes with grass and clay fascines as is done in the Godavery.

In the first place several ropes made of bark, or stalks of the green palmyra leaf, are arranged on the ground parallel to each other and about 18″ to 24″ apart, as shewn by *a*, *a*, *a*, ; on these is laid a quantity of the long grass called in Burma, "elephant" grass, but in the Godavery "lunka grass," (*lunka* meaning island); the grass is laid about 2 or 3 inches thick and with the stalks at right angles to the ropes below. On this grass is placed a layer of *clay* about 3 or 4 inches thick, which being wetted and rammed, the whole is rolled up like a roly-poly pudding (to use a homely simile); the ropes are tied round it, and the fascine then presents the appearance shown in *Fig.* 2. A sufficient number of these fascines being made *on the spot*, the operation of rolling them into their place is commenced, but previous to doing so, the bank, if too vertical, is sloped back from the edge of the water; and to prevent the fascines from rolling too far down in the river, stakes are driven in at the toe of the proposed spur, and made secure to the bank or each other.

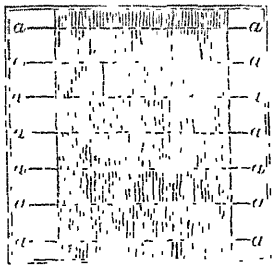



*Fig.* 1.

*Fig.* 2.

The fascines are then rolled in gradually till they reach the line of stakes (the spur may be made of any *width* required by using 2, 3, or more fascines placed in a line). Row after row of fascines are then placed in the same way excepting that occasionally a row instead of being placed *parallel* to the line of stakes is put *vertically*. Sharpened bamboos are driven into the fascines all over to pin them to each other. In a few days the grass with which they were made begins to sprout and grow, and in a short time a most efficient spur or groyne is made, which no

flood can remove. Care should be taken to look for the *toughest* clay, which is not easily dissolved by water; otherwise, if the earth is washed away, the stability of the whole spur is endangered.

*Fig.* 3, gives a rough idea of a side view of such a spur. The Engineer in charge of the works should himself decide on the best places to throw out these spurs, and the *details* may then safely be left to a Contractor, supervised by an Overseer, or Subordinate of the Department. In the Godavery, a Native Channel superintendent is often quite capable of superintending these works, which are so simple, that having only once seen it done, is sufficient for any ordinary intelligent native to understand the whole process. These spurs are very useful in removing sand-banks which are beginning to form in the bed of the river, and so endangering the banks by deflecting the current against them. I should think that a fringe of such "groynes" or "spurs" judiciously placed around the inside (western side) of the sharp bend on both sides of the Thambyadine Creek would most effectually preserve that bank from "caving in" as it is now rapidly doing, and if it be desired even to prevent the Thambyadine from getting any wider, one of these spurs on each side of its mouth projecting into the river some considerable distance, would answer the end at once. I have mentioned that these spurs are of great use in causing the removal of sand-banks. I may also state that *eradicating the grass* which begins to grow on these banks helps still further to get rid of such nuisances. Had some such measures as those now mentioned been adopted at Henzadah long ago, the river would now have been *close* to that town instead of the large sand-bank that is there.

*Fig.* 3.

This report has already reached too great a length, and as I am pressed for time also, I shall bring it to a conclusion by making only one more suggestion with regard to the Hline, or the Myitmaka river as it is generally called in its upper course.

The Chief Engineer in his Memo. of instructions to me, dated the 22nd February last, expresses a wish that the Hline "may be made a *navigable*" stream much further north than it is at present. I have given this wish my best attention, and I believe the Hline could *be*

*rendered a very good navigable Channel the whole way from Prome to Rangoon.* Immediately north of Prome, there is a very sharp bend of the Irrawaddy to the right ; in this bend on the Prome side, a Nullah or Choung, called the "Naweing" debouches; the Naweing rises in the hills N. N. E. of Prome, and when about a mile from the Irrawaddy receives from nearly due East the waters of another Choung, called the "Loothat-choung;" about 5 miles from the mouth of the "Naweing" and along the course of the "Loothat-choung" another small channel (the Zeechoung) running north and south is reached, through which, (I am informed by Sub-Overseer Sheer Mahomed, who knows the locality well) that waters of the Naweing and Loothat-choung, are conveyed *South* to Engmah swamp, and so to the "Myitmaka," when the floods in the Irrawaddy are high enough to dam those waters and prevent their flowing in their natural course, *i.e.*, into the Irrawaddy itself. The *lowest* level of water in the Irrawaddy at Prome is 160 above H. W. It has never been so low since I came to Prome, but Mr. Dunn, the Executive Engineer, took the levels in 1868, and he informs me that it went down to that. The *bed* of the Hline at Mengdoo, which is just 45 miles (measured on ... 3 o by Naweing, Loothat-choung and "Myitmaka" through the gulled up mah swamp, is 146 above H. W., or 14 *feet below lowest* water in the waddy at Prome, which gives a fall of between 3 and 4 inches a mile *Fig.* before the waters of the Irrawaddy, supplemented by the discharges es Naweing and Loothat-choung can be permanently diverted into the Hline the channels of these streams must be deepened considerably.

If the tradition that a large branch of the Irrawaddy once flowed down through the Hline from the spot where the Naweing now debouches is true, there will not be any great difficulty in excavating a channel, as it will be in *river deposit.* I have no reliable levels of this portion, but it would appear from the levels taken by Mr. Mackay last April, that the bed of the Loothat-choung 2 miles from its mouth, or about 3 miles from the Irrawaddy is 185·3 above H. W.; at 5 miles from the Irrawaddy it is 197. The bed of the Engmah swamp is 165 and the bed of the "Myitmaka" at the junction of the "Wetpouk" 163·89. The level of the bed of the Myitmaka where it is spanned by the Engmah bridge on the Poungday road is also 165. To make a *navigable canal which can be used throughout the dry season*, or about 6 feet deep, a portion of the cutting in the distance between the mouth of the Naweing and the 5th mile

on the Loothat-choung will be very heavy, not less than 43 feet, if the levels given above are correct. The heavy cutting will be for a *very little* distance only. From the 5th mile on the Loothat-choung towards the Hline, the depth of cutting will become rapidly less, being not more that 12 feet at the Engmah bridge and about 9 or 10 feet at the Wetpouk junction. Until a line of levels is run along the bed of the Naweing as far as the junction of the Loothat-choung, and for 4 miles up the bed of the latter, and thence down the nullah Zeechoung through the great swamp to Pyatha on the Myitmaka, it is not possible to say precisely what depth of excavation is necessary. All therefore that I can say at present is, that if no obstacle, such as rock, is met with in the beds of the Naweing or Loothat-choung, there will be no difficulty in cutting such a channel from the Irrawaddy to the Hline as I have proposed, and which shall be navigable all the year round. It will of course be necessary to place a lock at its head, as well as a set of head sluices to admit the waters of the Irrawaddy when necessary, or to shut off the supply when the Naweing, Loothat-choung and Wetpouk streams may happen to come down in full flood all together, and prove too much for the Hline.

When the population of this part of Burma is large enough to require that all the lands reclaimed in the delta by means of the embankment along the Irrawaddy, be taken up for cultivation, an event which may be looked upon as certain, *irrigation* will become a necessity as before remarked; and I can see no difficulty whatever in irrigating the whole of the basin drained by the Myitmaka and the Hline, from the latitude of Poungday downto Nyandoon if necessary. All that will be required to do so, is, to throw a weir of sufficient height across the Myitmaka above the junction of the Wetpouk, and cut two main distributary channels or rajbuhas, East and West, and running on the highest ground that can be reached by the water, and generally parallel to the course of the Myitmaka itself, with smaller irrigating channels leading from those in an oblique direction towards the Myitmaka or Hline, which itself will receive the whole of the drainage and carry it off. Should one weir not be enough for the whole distance traversed by the Hline, one or two more might be constructed at any points where it might be desirable to raise the surface of the water; and the navigabilty of the channel preserved by constructing locks alongside of the weirs.

In the accompanying tracing or index map I have shown the spot where

I have proposed to take off the irrigating and navigable channel above-mentioned; the direction of that channel as far as Mengdoo; the proposed site of the weir above Wetpouk junction; and probable lines of the two rajbuhas, with a few of the smaller irrigating channels. The thick line on this map shows the line levelled last April and May, and which I consider is the proper alignment for the marginal embankment generally.

It only remains, in concluding this report, that I should state that in dealing with the Irrawaddy I have followed the principles which guided the Engineers who planned and carried out so successfully the grand schemes on the Godavery and Kistna rivers, and on which I have now had nearly 15 years' experience.

I have endeavored to be perfectly accurate in all calculations given in this report,—or in the statements which accompany it. It is quite possible that where so much calculation was required, a few errors may be found, but I believe no error important enough to vitiate any of the deductions drawn in the report will be discovered. I have received from Sub-overseer Sheer Mahomed very efficient help; the greater part of the plans are drawn by him. Both Mr. Bell and Sheer Mahomed rendered me every assistance in taking the section of the river at Prome and the velocities. To Mr. Gordon, the Executive Engineer of the embankment division, my thanks are also due for the correctness and regularity with which the gauge registers under his charge were kept.

J. F. S.

PROME,
14*th September*, 1869.

TABLE OF AREAS, VELOCITIES AND DISCHARGE OF THE IRRAWADDY RIVER, AT PROME, CORRESPONDING TO VARIOUS HEIGHTS OF THE FLOOD OF AUGUST AND SEPTEMBER, 1869.

| Dates of observation. | Gauge reading reduced. | Area of each division of river section for each gauge reading. | Total area of section of river. | "Mean velocity," in "feet per second," | | | | | | | | "Discharge" in cubic feet per second "of each of the eight divisions." | | | | | | | | Total discharge for the river of each gauge reading. | True mean velocity in feet per second. | Velocity in miles per hour. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | B | C | D | E | F | G | H | A | B | C | D | E | F | G | H | | | | |
| 4th August. | 184 to 183 + H.W. | A 913<br>B 9,654<br>C 58,234<br>D 37,263<br>E 22,920<br>F 24,916<br>G 6 991<br>H 1,050 | 161,941 | *1·96* | *3 84* | *4 6* | *5·55* | *4·83* | *4·41* | *3·57* | *2·28* | *1,789* | *37,071* | *267,876* | *206,809* | *110,703* | *109,879* | *24,957* | *2394* | *761,478* | *4·7* | .. | |
| 2nd August. | 185 to 184 + H.W. | A 1,410<br>B 9,904<br>C 59,234<br>D 37,913<br>E 23,420<br>F 25,616<br>G 7,241<br>H 1,150 | 165,888 | 2·13 | 3·64 | 4 89 | 5 77 | 5·3 | 4·36 | 3.62 | 2·45 | 3,003 | 36,050 | 289,654 | 218,758 | 124,126 | 111,685 | 26,212 | 2817 | 812,305 | 4·9 | 3.33 | |
| 7th August. | | | | *2·02* | *3·57* | *4·5* | *5·72* | *5·0* | *4·69* | *3·32* | *2·35* | *2,848* | *35,357* | *266,553* | *216,862* | *117,100* | *120,139* | *24,040* | *2702* | *785,601* | *4·7* | .. | |
| 9th August. | 186 to 185 + H.W | A 1,910<br>B 10,154<br>C 60,234<br>D 38,563<br>E 23,920<br>F 26,316<br>G 7,491<br>H 1,250 | 169,838 | 2·15 | 3·57 | 5·5 | 6·2 | 5·26 | 4·79 | 3.83 | 2·5 | 4,106 | 36,250 | 331,287 | 239,090 | 125,819 | 126,053 | 28,690 | 31 25 | 894,420 | 5·2 | 3·54 | |

| Dates of observation. | Gauge reading reduced. | Area of each division of river section for each gauge reading. | Total area of section of river. | "Mean velocity," in "feet per second." | | | | | | | | "Discharge" in cubic feet per second "of each of the eight divisions. | | | | | | | | Total discharge for the river of each gauge reading. | True mean velocity in feet per second. | Velocity in miles per hour. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | B | C | D | E | F | G | H | A | B | C | D | E | F | G | H | | | | |
| 9th August. | 187 to 186 + H.W. | A 2,413<br>B 10,404<br>C 61,234<br>D 39,213<br>E 24,420<br>F 27.016<br>G 7,741<br>H 1,350 | 173,791. | 2·28 | 3 72 | 5 53 | 6·41 | 5·55 | 4 95 | 4·10 | 2·66 | 5,502 | 38,702 | 338,624 | 251,355 | 135,531 | 133,729 | 31,738 | 3591 | 938,772 | 5·4 | 3·67 | |
| " | 188 to 187 + H.W. | A 2,919<br>B 10,654<br>C 62,231<br>D 39,863<br>E 24,920<br>F 27,716<br>G 7,991<br>H 1,452 | 177,749. | 2·44 | 3·83 | 5·68 | 6·64 | 5·72 | 5·11 | 4·39 | 2·91 | 7,122 | 40,804 | 353,489 | 264,690 | 142,542 | 141,628 | 35,080 | 4225 | 989,580 | 5·56 | 3 78 | |
| 14th August. | 189 to 188 + H.W. | A 3,428<br>B 10,904<br>C 63,234<br>D 40,513<br>E 25,420<br>F 28,416<br>G 8,241<br>H 1,560 | 181,716. | 2·61 | 3 95 | 5·7 | 6·96 | 6·0 | 5·3 | 4·77 | 3·13 | 8,947 | 43,070 | 360,433 | 281,970 | 152,520 | 150,604 | 39,309 | 4883 | 1,041,736 | 5·7 | 3·87 | |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16th August. | 190 to 189+H.W. | A 3,940<br>B 11,154<br>C 64,234<br>D 41,163<br>E 25,920<br>F 29,116<br>G 8,491<br>H 1,670 | 185,688. | 2·75 | 4·04 | 5·73 | 7·04 | · 03 | 5·37 | 5.05 | 3·26 | 10,835 | 45,062 | 368,060 | 289,787 | 156,297 | 156,352 | 42,879 | 5,444 | 1,084,718 | 5·8 | 3.94 |
| 17th August. | 191 to 190+H.W. | A 4,455<br>B 11,404<br>C 65,234<br>D 41,813<br>E 26,420<br>F 29,816<br>G 8,741<br>H 1,782 | 189,665. | 2·88 | 4·13 | 5·72 | 7·5 | 6 20 | 5·54 | 5 26 | 3 3 | 12,830 | 47,098 | 373,138 | 313,597 | 163,804 | 165,180 | 45,977 | 5,880 | 1,127,504 | 5·9 | 4·0 |
| 18th August.<br>31st August.<br>1st September.<br>2nd September. | 192 to 191+H.W. | A 4,973<br>B 11,654<br>C 66,234<br>D 42,463<br>E 26,920<br>F 30,516<br>G 8,991<br>H 1,896 | 193,647. | 3·02 | 4·15 | 5·81 | 7·58 | 6·64 | 5·90 | 5·28 | 3·47 | 15,020 | 48,365 | 384,820 | 321,870 | 178,750 | 180,045 | 47,470 | 6,580 | 1,182,920 | 6·1 | 4·15* |
| | | | | *2 47* | *3·99* | *5 4* | *7·02* | *6·03* | *5·7* | *5·11* | *3 2* | *12,283* | *46,500* | *357,663* | *298,090* | *162,327* | *173,941* | *45,944* | *6,067* | *1,102,815* | *5·7* | .. |
| 19th August.<br>20th August.<br>30th August. | 193 to 192+H.W. | A 5,498<br>B 11,904<br>C 67,234<br>D 43,113<br>E 27,420<br>F 31,216<br>G 9,241<br>H 2,011 | 197,637. | 3 07 | 4·18 | 5·86 | 7·52 | 6·64 | 6·04 | 5 08 | 3·5 | 16,874 | 49,758 | 393,991 | 324,210 | 182,068 | 188,545 | 46,944 | 7,038 | 1,209,428 | 6·12 | 4·17 |
| | | | *46* [illegible] | *2·52* | *43·9* | *6 03* | *7·02* | *6·03* | *5·7* | *5·35* | *3·4* | *13,854* | *52,258* | *405,421* | *302,653* | *165,342* | *177,931* | *50,776* | *6,837* | *1,115,072* | *5·9* | .. |
| 21st August.<br>27th August.<br>28th August. | 194 to 193+H.W. | A 6,023<br>B 12,154<br>C 68,234<br>D 43,7·3<br>E 27,920<br>F 32,916<br>G 9,491<br>H 2,126 | 202,627. | 2·98 | 4 3 | 5·94 | 7·56 | 6 45 | 5·86 | 5·16 | 3 47 | 17,948 | 51,412 | 405,310 | 330,850 | 180,084 | 192,888 | 48,973 | 7,380 | 1,234,845 | 6·1 | 4.16 |
| | | | | *2·5* | *3·9* | *5·7* | *7·52* | *6·2* | *6·25* | *5·37* | *3·3* | *15,057* | *47,400* | *388,933* | *329,097* | *173,104* | *205,725* | *50,966* | *7,015* | *1,217,297* | *6·0* | .. |

* " Discharge " found by Mississippi Formula = 1,181,820 cubic feet per second.

| Dates of observation. | Gauge reading reduced. | Area of each division of river section for each gauge reading | Total area of section of river. | "Mean velocity," in "feet per second." | | | | | | | | "Discharges" in cubic feet per second " of each of the eight divisions. | | | | | | | | Total discharge of the river for each gauge reading. | True mean velocity, in feet per second. | Velocity in miles per hour. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | B | C | D | E | F | G | H | A | B | C | D | E | F | G | H | | | | |
| 23rd August.<br>24th August.<br>25th August.<br>26th August. | 195 to 194 + H W | A 6,548<br>B 12,404<br>C 69,234<br>D 44,413<br>E 28,420<br>F 32,616<br>G 9,741<br>H 2,241 | 205,617. | 3·01 | 4·27 | 6·07 | 8·15 | 6·75 | 6·25 | 5.58 | 3·49 | 19,710 | 52,965 | 420,250 | 361,965 | 191,835 | 203,850 | 54,355 | 7820 | 1,312,750 | 6·38 | 4 36* | |
| | | | | *2·71* | *4·18* | *5·94* | *79·4* | *6·24* | *6·45* | *5.54* | *3·3* | *17,745* | *51,848* | *411,250* | *352,639* | *177,340* | *210,373* | *53,965* | *7395* | *1,282,555* | *62·3* | .. | |

* " Discharge " found by Mississippi formula = 1,300,943 cubic feet.

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*Executive Engineer,*
*Irrawaddy Survey Division.*

# No. CCXCIII.

## THE FAIRLIE ENGINE.

*Memo. on the Fairlie Engine; by a State Railway Engineer.*

*To the Editor.*

SIR,—So much interest has been excited at home in the performances and design of the Fairlie Engine, and these performances have been so far identified with a question of paramount importance in India, that of Light and Narrow Gauge Railways, as will doubtless have caused many Indian Engineers to review for themselves the *pros* and *cons* of the whole question.

In doing this, the published information that is available will be found so scattered over a series of years, and private evidences so contradictory, that I have ventured to hope that a concise embodiment of the nett results of what I have gathered for myself on the subject may not be without interest for others of the Profession; and I therefore send you the following paper, which contains the notes I have made on the subject—strung somewhat loosely together—and would merely beg you and your readers to accept it, not as an attempt to exhaust the whole matter, but simply as a contribution in aid of a solution of what is, perhaps, the Engineering question of the day.

Your obedient Servant,

J. R. B.

*P.S.*—Since the above and the paper which follows, were written, my attention has been called to an able paper by Mr. Hawkshaw, the eminent Engineer, bearing upon a part of the same subject. Singularly enough, he

arrives upon some points, at exactly the same conclusions as myself, a result from which I would have derived some gratification had my paper been so fortunate as to have had an earlier publication.

It may be well to mention, for the benefit of those less intimate with Railway Polemics, that Mr. Hawkshaw's reputaion in the profession stands mainly upon his clear-sighted apprehension of such questions as that of the gauges, as his reports, to which he now refers, upon the Great Western Railway are not only models of perspicuity, but like his more recent remarks upon the Suez Canal, have the rare merit of having been verified to the letter by subsequent facts.

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All the engineering world has long been aware of the existence of Mr. Fairlie and his engine, and that, from whatever cause, he met with no more success than is usual when startling innovations upon long established custom are proposed. It is also notorious that the usual re-action has at length taken place, and that some few engines have been built and worked at home with such results as have called for the deputation of *Special Commissioners* from the "Daily Telegraph" and other newspapers of higher scientific pretensions, who have produced such glowing reports, as seem to indicate the inauguration of a new era in locomotives, and even in railways. It is very generally asserted that by this plan a large traffic can be carried on upon lines whose construction shall be so much cheaper than those of the old style, as to warrant the introduction of railways into districts, which, up to the present time, could not have supported them.

It is here proposed to examine into these pretensions, and into the system itself as expounded:—

i. In Mr. Fairlie's own pamphlet.

ii. In the published drawings and descriptions of the engines he has had built.

iii. In the published reports of various trials.

iv. And in the public and private criticisms which have reached the present writer.

Mr. Fairlie's pamphlet is dated in 1864, and is cast in the somewhat novel form of a dialogue between W., the writer, and E. an Engineer, who would seem to have made locomotives his specialty. It is needless to tell that E. makes but a poor fight for the system he is put up to advocate. Like the conventional unbeliever with whom some Reverend

Gentlemen are fond of carrying on an imaginary, and very one-sided, E. controversy, is drawn into heaps of the most damnatory admissions, and outvies the unbeliever in making such haste as is scarcely decent to accept all that W. advances, while he carefully avoids putting questions on the only points about which any doubt exists.

The defects of the existing system which E.'s candour and W.'s astuteness establish may be summarised as follows :—

(A).—That a separate tender to carry water and fuel involves 10 times the dead weight used in constructing tanks and coal bunkers on the frame of the locomotive itself.

(B).—That tank engines are of limited application, unsafe to be run backwards, unable to carry sufficient fuel and water for long runs except upon more wheels, and that the extended wheel base thus involved would, if tried, prove dangerous upon curves.

(C).—That to obviate this difficulty, single bogies have been tried with very indifferent success, and double bogies, that is, engines carried upon two trucks, each capable of accomodating itself to the line, do not appear feasible, from the difficulty of transmitting power to the wheels.

(D).—That from 8 up to 11 tons on one pair of wheels cannot be exceeded without serious detriment to the permanent way even ; that 14 and 16 have been, and are now, used for passenger engines, but that modern practice has found this so destructive of rails and tyres, as to give the preference to passenger engines with 4 wheels coupled, notwithstanding that the friction of the coupling rods produces a loss of power, in an increasing ratio to the number of couplings and the speed attained.

(E).—Two smaller engines, coupled back to back, are preferable to one very large one with all wheels coupled, each engine accomodating itself separately to curves, and having its own wheels coupled together. One driver could not, however, be depended upon to work both machines.

(F).—That engines with interchangable parts are a great desideratum, although very few steps have been made to attain that object. That by this means, less capital would be locked up in engines under repair, and a less numerous staff of workmen required, if a broken part could be at once replaced and a new one made at leisure, instead of under the pressure that is put on the work when a whole engine is idle for the want of a single part. And that 12 per cent. in the first cost of engines might be saved under this head alone.

(G).—That he, E., is too much occupied, and works too much in the groove of established routine, to be able to scheme improvements upon the crying evils he so clearly perceives.

After extracting this information from the " Engineer," W. propounds that *he* has a design which overcomes all the above objections, and classes its advantages under the following six heads :—

" 1st.—By the construction of the boiler, which is so arranged that a greater generating and maintaining power can be obtained, than is possible under the existing system.

" 2nd.—By every ounce weight of the engine, including fuel and water, being made available on the rails for traction power.

" 3rd.—By tenders being entirely dispensed with, as *useless, unremunerative and costly.*

" 4th.—By the general arrangement of the engine complete, by which it is enabled to pass round any curves down to a radius of 1½ chains, with the greatest facility, and the friction due thereto is reduced to a minimum.

" 5th.—By doing away entirely with the costly arrangement of turn-tables at termini and locomotive depôts."

" 6th.—And lastly, by reducing the expenses of the repairing establishment to the minimum, together with the expenses arising from the want of a system of duplicates, as by the plan proposed, the most complete system of duplicates can be carried out."

In the conversation that follows, W. explains under the first head, that his boiler is, let us say, double the ordinary length, with the fire-box in the middle, and as it would appear, practically equivalent to two ordinary engine boilers joined together, fired at one operation.

Complicated arrangements, for passing the heated gases from the smoke-box, once or even twice through the steam, so as to super-heat it, are indicated; but as might have been expected, no trace of this part of the project is to be found in the actual engines as now constructed. W. adds that the firing is done on one side, the driving on the other. The driver can, however, have a door or sight-holes through which to examine the fire; 2 feet 5 inches of space from shell of fire-box to outside of foot-plate is available, and the friendly interlocutors admit (the present writer is not in a position to say with how much truth) that this is more than is allowed for both driver and stoker on ordinary tank engines.

Here the adverse critics differ materially from Mr. Fairlie.

The heat on the foot plate is reported to be unbearable, even in England, and it is prognosticated that grave inconvenience may at times arise from the inability of the driver to keep a look out from either side of his engine, and the impossiblity of the fire-man taking the driver's place in a case of accident or indisposition.

It may be added on the other hand that the expedient of casing the fire-box as is universally done in India, and, of having the regulator, reversing lever, and injectors arranged so as to be worked from either side, will go far to obviate these undoubted defects.

The explanation of the second head developes the fact that coal bunkers and water-tanks are carried on the same frame or frames, and that so many wheels, all drivers, are placed under the machine as that no pair of wheels is loaded with more than 10 tons. The long wheel-base difficulty is avoided by the boiler being carried on two separate frames, each at liberty to accomodate itself to a curve, each with its own cylinders and other gear to drive its own wheels which are coupled together, each in fact a locomotive engine in all but the boiler.

Under the third head, it is claimed that such an engine could carry water and coal for a run of, say, 80 miles. It is difficult to see why the two tank locomotives into which this one engine might be resolved, by substituting two separate boilers for the one double boiler, could not do the same.

The fourth head is sufficiently dealt with under the second; details are added of the means proposed for connecting the boiler with the bogies, so as to avoid any strain by their own weight, by the pull of the engines, or by their expansion and contraction, upon the boiler and fire-box.

These contrivances are more ingenious than practical, and it is understood that they have now been entirely abandoned by the inventor.

The fifth head is disposed of by the engine being alike at both ends.

The last head is got over by E. himself, who professes to see that all the parts are interchangeable with the greatest ease. It would appear that only one whole boiler with tanks, bunkers, foot-plates and boiler fittings complete, or one whole bogie with cylinders, wheels, rods, valves, and gear entire, are to be exchanged at one operation. It is not stated why ordinary locomotives might not be similarly treated, nor is it clear that in 1864 Mr. Fairlie anticipated that with more mature experience he would be able, from time to time, to introduce such beneficial changes

into his system as effectually to preclude the idea of interchanging the parts of a new engine with one of earlier date.

Divested of those peculiarities which practical experience has eliminated from the design set forth in the pamphlet, the Fairlie engine of to-day may be described with sufficient accuracy as a modification of the older plan, which has recently been improved upon by other inventors, of two tank engines coupled, known technically as a double or twin tank engine. Mr. Fairlie's modification consists, in separating the frames with the wheels, cylinders and motions attached to them from, the boilers.

For the two boilers he substitutes one—or rather, he forms one boiler out of the two—by merely joining their fire-boxes together so as to allow of their being fired at one operation, and of the same pressure of steam pervading both. The smoke-boxes, chimneys, safely-valves, tanks, feed injectors, regulators and boiler-fittings generally, remain the same in both.

The overhanging foot-plates of the twin engine are replaced by others at the sides, where it is natural to expect that they are somewhat cramped, and the whole of this part of the arrangement is supported and stiffened by a carrier-frame, which, in its turn, rests upon bogie pins strongly secured to the lower frames—which represent the frames proper of the double engine.

These frames being free to accomodate themselves to the curves of the rails, it is necessary to provide such a connection between the steam pipes from the boiler to the valve chests, and from the exhaust ports to the chimney blast pipes as will admit of the bogie frames swivelling under the boiler, and at the same time allow some play in a vertical plane for the jolting of the bogies as they follow the inevitable inequalities of the road. The pamphlet is silent upon the subject of this mechanism—and its silence is the more to be regretted, as this is the very point which is attacked by the adversaries of the Fairlie.

The present writer has met with a rumour that the original manufacturer of these engines gave them up after much patient experiment, from a conviction that it was impossible to keep the steam-pipes tight; and another rumour, which may be more easily tested, has it that the Fairlie engines made for the Queensland railway have never been used, owing to their defects in this particular. All that can be gathered from the published drawing of the " Little Wonder," is that a radius pipe is hinged

at the top to the boiler steam pipe—where the latter protrudes into the smoke-box, and at the foot to a projection from the valve-chest—the steam passing through both hinges, as it does through the trunnions of an oscillating engine. To the two steam-tight joints thus involved, we must add one on the radius pipe itself, to allow of a telescope motion, making a total of three steam-joints to each bogie, or six to each engine complete.

At the best, it must be expected that a great deal of labor will be required to keep these joints tight, nor is it to be wondered at, when their number is considered, and the jolting, hammering action of a locomotive on ordinary roads taken into account, if doubts exist in many quarters of their continued efficiency.

Both sets of valve gear are actuated by one reversing lever, or screw, and both the regulators by one handle.

If we look at the latest developments of the locomotive on English narrow (4 feet 8½ inch) gauge railways, we shall not only find a *raison d'être* for the Fairlie method, but we shall find that it, or something very like it, arises naturally from the conditions which the home railways offer.

In the first place, locomotives of the ordinary type have reached as large a diameter of boiler as the gauge admits of, and as great a length of barrel and tubes (something under 11 feet) as can be constructed with economical advantage; notwithstanding which, the traffic still calls for engines capable of drawing heavier trains, not only because heavier trains reduce the percentage of cost for management, but also because the number of goods trains is now so great, as to increase the risks of accident very materially.

The call which has thus arisen for powerful engines, is intensified by the introduction of steeper grade and sharper curves, upon recent lines, and can only be met by throwing two engines into one, or at any rate so joining them as to be under one control.

In the next place, after the weight placed upon the driving wheels has been augmented to the utmost, and increasingly expensive *Roads* been introduced, and successively hammered to pieces, it is found that the maximum weight upon locomotive wheels must be reduced. Recourse has been had to the coupling of two or more pairs of wheels to obtain *bites*, but it seems to be definitely settled, that for high speeds, no more than two pairs of wheels should be coupled, nor even for low speeds more

than three. Mr. Fairlie accepts this canon and still utilises all his wheels by dividing them into two separate sets, each with its own motive power. In fact, subject to the doubt that hangs over his steam pipes, and to a comparison between his system and twin tank engines with their regulators, and, perhaps, valve gears coupled, there can be no doubt that Mr. Fairlie has produced an engine which goes far to meet the requirements of all lines where the traffic is in excess of the capabilities of the gauge, be that gauge 1 foot 11½ inches or 4 feet 8½ inches.

As they must have more powerful engines, he gives them two engines combined into one. Since 11 feet must not be exceeded for the length of the tubes, he puts his fire-box in the middle, and gets his 11 feet on each side.

When they demand the coupling of the wheels, without the frictional loss which occurs when a long series is connected, he divides his wheels and couplings into two sets.

And when they require the engine to traverse sharp curves with ease and safety, he shows at his engine works at Hatcham, that he can run his engines round and round the yard, at such speeds and over a circle of such small radius, as to excite the amazement of all who have seen it.

The Fairlie engine may thus be taken to be a most marked advance in the science of locomotive engineering, in all cases where the traffic to be worked approaches to the maximum capabilities of the gauge which may have been adopted, and it now remains to be considered how far his engines meet the case of lines where the capabilities of the gauge are considerably in excess of the traffic, as will probably be the case for many years in India, more especially upon branch lines, if constructed to the standard gauge.

Where the gauge of a line is considerably in excess of what is required by the traffic, cheapness in the first cost of the line may be taken as *the* prime necessity.

In order to design the cheapest line, the first point is to ascertain what lighest form of vehicle for passengers and goods can be devised for the efficient working of the traffic; and here we may, from past experience, at once set it down that such vehicles will, upon a line of 5 feet 6 inch gauge, carry a gross weight of not much less than 6 tons upon one pair of wheels, a weight very much less than that ordinarily put upon one pair of wheels of an engine.

Having ascertained the weight on the wheels of the vehicles, it is clear that the maximum of constructive economy will be attained by reducing the weight upon the engine wheels to the same standard, and using the cheapest form of permanent way that shall be adequate to this minimum weight.

In countries like South Australia and Egypt, where a standard gauge had already been adopted, and so far carried out as to make a break of gauge open to many serious objections, an approximation to this method has been introduced. The results are, even upon the present system of locomotives, a financial success; but it is found necessary to use engines somewhat heavier than thus indicated, and even then the trains that can be taken are but small.

Mr. Fairlie's method, or that with which alone a comparison remains to be made, that of coupled tank engines, offers a means of extending the utility of this class of line to a very great extent. Mr. Fairlie has figured in his pamphlet an engine on two sets of 4 wheels, with no more than 6 tons on each pair of wheels, capable, as he alleges, of drawing 225 tons up a grade of 1 in 100 at 20 miles an hour.

Allowing even that he has overestimated its capabilities, and admitting that on a 5 feet 6 inch gauge, the dead weight of the engine would be considerably greater, we may venture to take it that, with 6 wheels in each bogie, an engine can be made, quite equal to drawing a train of 20 or even 25 loaded wagons up 1 in 100 without exceeding the unit of weight on each wheel of the wagons themselves, a result quite equal to the probable requirements of branch lines, if not to those obtained upon existing Indian railways.

It is scarcely within the scope of this paper to enter into the wide question of gauges. Is is sufficient to say that the Indian gauge is in itself a standing admission on the part of the old warriors of the battle of the gauges, that their cherished 4 feet 8½ inches was too small; but whether that be so or not, the Great Western Railway, with its shares not worth half their nominal value, and its present costly system of a double gauge to enable it to carry through traffic and still use up its old rolling stock, is an undeniable protest against diversity where uniformity can be obtained at a reasonable cost. It may be well, therefore, very briefly to discuss the relative cost of a line to standard gauge with the light rails which the Fairlie engine would admit of, and of a line to a narrower gauge.

The great question is that of Rails: a very difficult one from an *à priori* point of view, but which may perhaps be solved by a reference to existing lines; for instance, the South Australian light railways have a 5 feet 3 inches gauge and 40 lbs. rails.

The Alexandria and Ramli line has 4 feet 8½ inches gauge, and 38 lbs. rails.

The Festiniog line has 1 foot 11½ inches gauge, and 48½ lbs. rails.

All these lines work satisfactorily, and in none of them is any change in the weight of rails contemplated at present.

The inferences to be drawn from this absolutely inverted scale of ratios would seem to be—

1st. That the Festiniog traffic has already exceeded the fair capacity of the gauge.

2nd. That the constructors of light lines seem to have decided on making the weight of their rails inversely as their cost.

3rd. That a rail of, say, 42 lbs. is heavy enough for light lines to Indian standard gauge, a conclusion which it will be difficult to gainsay, taking 3 tons per wheel as the maximum weight to be carried; and,

Lastly, That no rail much under 42 lbs. can be used at all.

An iron permanent way with this weight of rail may be safely estimated to be delivered at an Indian seaport for £600 per mile less than that, for instance, of the G. I. P. Railway with its 68 lbs. metals and pot sleepers to match, and if it be allowed that the New State Railways, will many of them have their origin three or four hundred miles up country by rail, with possibly an average cartage of 30 miles from the nearest railway station, the total saving on the first cost of permanent way on the system now under notice, would not fall short of £1000 per mile, as compared with existing railways.

From the instances that the present writer has been able to gather, it does not, as already stated, appear that less than a rail of about 40 lbs. has stood the test of practice upon any gauge: much less might doubtless be used with a system of longitudinal timber sleepers, but these are unfortunately out of the question in an Indian climate, where the wood can not fail to warp and twist the road out of line and out of gauge. It will therefore be assumed in what follows that the same rail will be requisite on whatever gauge may be thought expedient.

The difference between broad and narrow will then stand, per foot of gauge per mile, with permanent ways both wholly of iron:—

*Tie-bar*, .. 1760 × 1 foot × area of tie-bar cross section, or say 4 cwts. of wrought-iron.
*Ballast*, .. 5280 × 1 foot × 1 foot 9 inches = 9,240 cubic feet.
*Earthwork*, 5280 × 1 foot × say 6 feet = 31,680 „
Ordinary bridges and culverts, 1 foot × aggregate longitudinal section of bridges, &c., say 1000 cubic feet of masonry.

These items would not, at average prices, amount to more than Rs. 700, a fact which might if requisite be verified by a reference to the prices now being paid on lines actually under construction. It is true that where heavier works are required, the absolute saving per foot of gauge is proportionably greater, as far as the earthwork is concerned, but many sound engineering authorities object to reduction in the width of bridges below 12 or 15 feet, where these works are of any considerable height. Indeed, the present writer is fully convinced that in an ordinary Indian line of country, Rs. 700 per mile is quite as much as can be saved by a reduction of a foot in the gauge, believing, as he does, that 6 feet height of bank or depth of cutting is a very fair average for lines with gradients of 1 in 100, and such curves as the class of engines under discussion will freely admit of.

In the matter of rolling stock, it is somewhat difficult to arrive at a comparison of the respective cheapness of broad and narrow gauges. That the Festiniog railway, for instance, requires much less dead weight of wagons in proportion to the freight is scarcely to the point,* as the freight consists almost entirely of heavy minerals. It does not appear that a freight, for example, of half pressed cotton could be carried so advantageously, unless the bodies of the wagons were so much wider than the gauge as to endanger their stability. Such overhanging vehicles would demand a greater proportional width in rock cuttings, bridges, tunnels, and so forth, than the stock of the existing lines, nor is it easy to see how railway travelling in the hot weather could be made endurable in the cooped up carriages of a very narrow gauge.

In any case, a new gauge would require a complete rolling stock of its own, equal, not to the average, but to the maximum, requirements of the traffic. A narrow gauge branch from one of the standard lines, might

* Mr. Fairlie's paper read at the last meeting of the British Association, appears to claim this as the special advantage of a narrow gauge line.—[ED.]

possibly need double the amount of new stock which would suffice were it in a position to draw upon the parent line in case of emergency; and at the junction, two trains would be out of profitable employment while a cargo was being transferred from one to the other.

It would thus seem that even if the narrow stock is in itself cheaper than the broad, its use on isolated branch lines would not prove economical. However light the actual cost of transferring goods might be, and however little the natives may value the time occupied in this process for their persons or their goods, it must still be remembered that fragile wares are liable to serious damage. At home, various classes of coals are said to be deteriorated from 5 up to even 20 per cent. in value in this way.

Whether these views of the relative merits meet with full acceptance or not, it is hoped that, at any rate, so much can be said for the wide gauge with light rails as to make the bearing of the Fairlie engine upon its capabilities of some interest. Mr. Fairlie can give us an engine with only 3 tons on each wheel, capable of pulling such trains as are now ordinarily despatched along main lines, and if such engines stand the test of practice, they will eliminate the disturbing element which heavy locomotive wheels have hitherto introduced into the attempts to formularise the life of rails, and it will be found exactly true that their durability is inversely as the product of the gross weight and speed.

Whether for any class of line, the Fairlie engine is so good as the two tank engines, to which it is so nearly equivalent, depends in a great measure upon the reliability of the steam connections of the former. In cost they cannot be far different, and if, as seems probable, the tanks will require less running repairs and be more convenient for the men, they will on the other hand be less effective from the inequality of the steam-pressures in the boilers; and, however tightly coupled together, possibly more destructive to the permanent way. The tanks, however, avoid the proverbial objection to putting all our eggs in one basket. A broken down Fairlie engine would be utterly useless, while one of the two tanks would surely be able to draw part of a train, and on Mr. Fairlie's own method of "interchanging parts," he would require at least a spare boiler with tanks and fittings complete, and also one spare bogie, altogether equal to a whole tank engine and a boiler besides for the repair of one engine. Common sense would surely demand another bogie, so as to make a

second engine complete, and even then no more efficiency could be expected than from 3 duplicate tank engines, which would still be fit to keep some traffic moving, were two of them disabled on a branch which only required one Fairlie, or one pair of tanks to work it.

*Note.*—It may perhaps be thought by those who have accustomed themselves to consider the Fairlie in the light of one single engine that its consumption of coals must be much less than that of twin tanks.

This, it will be seen, is equivalent to claiming for it a power of producing more steam power from a given amount of caloric than any other engine, an illusion which is quite dispelled by the report in "The Engineer," No. 718, dated October 1st, 1869. It is there stated that the "Little Wonder" consumes over 50 lbs. per train mile, "*or about double that of an ordinary well proportioned passenger engine,*" and it is stated further on, that the single tank engines on the same Festiniog line consume only 22 lbs. per train mile.

The same report, although highly favorable to extremely narrow gauges, contains much information bearing upon the points mooted in this paper, notably upon that of the Festiniog traffic being in excess of the capability of the gauge. It says, "It is very easy to build engines which will suit a narrow gauge line, so long as the loads are kept to narrow gauge proportions; but when we find loads approximating to those carried on the 4 feet 8½ inch gauge thrown upon the 2 feet gauge, the problem does not admit of such easy solution."

J. H. B.

## NOTE ON THE FAIRLIE ENGINE. BY CRAWFORD CAMPBELL, ESQ., SUPDG. ENGINEER, INDORE STATE RAILWAY.

The object of this note is to ascertain the actual value of the Fairlie Engines, by tabulating and comparing such data as can be collected regarding their performances and those of other Engines of the ordinary type which have been designed for working heavy loads up steep inclines.

The information thus collected is shown in the accompanying table. It has been compiled from notices scattered through the various professional and home journals; from papers published by the Government of India; and from the Transactions of the Institution of Civil Engineers, as republished in the Roorkee Professional Papers; and from a small pamphlet edited by Mr. T. W. Armstrong, C.E., Officiating Chief Engineer of the Central Provinces.

The results of the various experiments have been very imperfectly recorded. The state of the rails and of the weather at the time; the amount of fuel expended; the dimensions of the grate and heating surface; and the action of the steam in the cylinders, are given in very few instances. To reduce the performances recorded to one common measure, I have had to assume a value for the constant resistance of the train. To Clarke's value of 8 lbs., I have added 38 per cent. for sharp curves, side winds, and imperfections in the road, making the constant resistance 11 lbs.

Only those trials which are fully and satisfactorily recorded have been selected, all those where the data were incomplete or open to suspicion have been carefully* eliminated. As the piston area and the pressure of steam in the cylinder form the most important items in calculating the effective tractive force of a locomotive, I have selected as the best modulus of comparison, *the amount of tractive force exercised per square inch of piston area for every pound of steam pressure in the cylinder*, which seems the fairest test of the relative power of each engine. The results will be found in the last column but one; and in the next and last column these are reduced to a common measure so as to show them at a glance: the highest among them, that given by the Semmering engine, being taken as 1,000, and the others reduced to the corresponding ratio.

* Amongs them, I regret to say, all the "Mountaineer's" trial.

Measured by this standard the following is the order in which they stand:—

1. Semmering incline engines.
2. Tongoi railway „
3. Giovi incline „
4. Bhore Ghât „
5. Mauritius railway „
6. The Welsh Pony.
7. Norwegian railway „
8. Little Wonder (*Fairlie*).
9. Santiago and Valparaiso goods engines.
10. The Progress (*Fairlie*).
11. Sweedish railway engines.
12. Santiago and Valparaiso passenger engine.
13. Brœlthal railway engine.

It will thus be seen that, where engines of the ordinary type have been expressly designed to work heavy loads up steep inclines, they are, as a rule, more powerful than any existing Fairlie Engine: even the much abused "Welsh Pony" bears away the palm.

What then is the secret of her defeat? the cause is not far to seek: she failed because she was deficient in steam generating power. The area of grate and heating surface is not given; but that it was decidedly deficient is evident from the fact that, although the boiler was guaranteed by the makers to work up to 160 lbs. ordinarily, and 200 lbs. on special occasions, it only accomplished 150 lbs. when pushed to the uttermost, and this speedily fell to 125 lbs. Her inability to keep up steam of a high pressure for any length of time is very marked. Thus, in one of the experiments tried before the Russian Commissioners, she started up an incline of $\frac{1}{85}$ with a pressure of 140 lbs., which fell to 130 lbs. after she had run one quarter of a mile; whilst the "Little Wonder," starting at the same point with 170 lbs. had, after running the same distance, that pressure still registered.

The following table shows clearly the relative steam generating power of the two engines.

| Registered boiler pressure | Little Wonder | | Welsh Pony | | |
|---|---|---|---|---|---|
| | 1 | 2 | 1 | 2 | 3 |
| | lbs. | lbs. | lbs. | lbs. | lbs. |
| At starting, .. .. .. .. .. | 160 | 160 | 147 | 140 | 140 |
| At stopping, .. .. .. .. .. | 140 | 135 | 138 | 138 | 120 |
| Maximum, .. .. .. .. | 170 | 160 | 150 | 150 | 145 |
| Minimum, .. .. .. .. | 135 | 135 | 125 | 132 | 120 |

The "Welsh Pony" was designed with a specific object in view, viz., to

carry loads of 35 tons at 10 miles an hour up a certain incline. When the traffic increased beyond this limit, the "Little Wonder" was ordered with the express intention that she should be more powerful than the "Welsh Pony" and perform greater tasks. What can be more absurd, therefore, than to pit the one against the other, and then to describe the inevitable triumph of the more powerful engine as a legitimate proof that the *system* on which it is built is better than that on which the weaker locomotive is put together? It is clear that, had the "Welsh Pony" been designed with a larger grate and more heating surface (which could easily have been done), she would have been able to drag as heavy loads, in proportion to the number of her cylinders, as the "Little Wonder."

Neither is it fair to compare the Brœlthal engines with the "Little Wonder;" the traffic on that line is very small, and all goes down hill, so that the locomotives are mainly required to drag light trains of empty wagons up the incline, and they were designed accordingly to work with a very low steam pressure, and have, in consequence, a very limited grate and heating area.

I notice that in the contests between the "Welsh Pony" and the "Little Wonder" they were not handled on equal terms: the former cut off uniformly at one-third stroke; the latter, in her principal performance, at two-thirds.

Comparing the progress with other broad gauge locomotives, her inferiority to them is very marked: the Semmering, Giovi and Tongoi engines being 33 per cent. more powerful, the Mauritius and Bhore Ghât 25 per cent., thus again showing that, where engines on the old type were expressly designed for steep inclines, they have beaten any Fairlie engine yet turned out. The most noteworthy fact about them is the low pressure at which they work, as will be seen from the following comparison of average cylinder pressures:—

| | | | lbs. | | | lbs. |
|---|---|---|---|---|---|---|
| Semmering Engines, | .. | .. | 56 | | | |
| Tongoi ,, | .. | .. | 55¾ | | | |
| Giovi ,, | .. | .. | 56 | Progress, | .. | 94⅔ |
| Bhore Ghât ,, | .. | .. | 56 | | | |
| Mauritius ,, | .. | .. | 77 | | | |

Herein, in fact, lies the whole secret of the power of the Fairlie Engines—*a high working rate of steam pressure.* This, combined with their doubled number of cylinders and double boiler, has enabled them to perform the tasks of which so much has been lately written.

As regards these latter points there is no novelty about their application. The Giovi engines are simply two tank locomotives, coupled tail to tail, so as to have a joint foot-board and driver. They have thus all the advantages claimed for the Fairlie type, viz., shortness of wheel base, increased cylinder and boiler power, and freedom of motion either backwards or forwards; whilst they possess one great advantage—if the exigencies of the traffic require it, they can be separated and used as two distinct locomotives.

As regards the main peculiarity of the Fairlie engine, viz., high working pressure, it should be borne in mind that this means increased consumption of fuel, and consequently enhanced cost of working. It is not, therefore, easy to accept the assertion made by Mr. Spooner (of the Festiniog line) that the Fairlie engine used less coal and is more economical than engines of the ordinary type. Until duly tabulated experiments have been made, and published, no satisfactory conclusion can be arrived at on this point.

We are now in a position to analyse the claims put forth by Mr. Fairlie and his supporters, and to learn how far they are justified by the facts recorded in the annexed table, and in the reports of the various trials. They are as follows:—

*First.—Reduction of wear and tear of permanent way owing to the use of the double bogie.* This may be accepted without reserve, the question is whether other systems of bogies, and even the Giovi pattern when properly coupled, may not be equally efficacious. Information is required on this point.

*Second.—Diminished oscillation.* This seems to be a fact, but it has been denied by Mr. Berkeley; and in comparing the "Little Wonder" with the "Welsh Pony," it should be remembered that the latter has only 4 wheels, and is notoriously "*a Boxer*," so that she is a very rough and unsteady specimen of the ordinary type, and a comparison with her is therefore unfair to that system.

*Third.—The Fairlie engine can move equally well either way, and requires no turn-table.* This advantage is common to the Giovi pattern.

*Fourth.—Great adhesive power, (all the wheels being drivers,) combined with a very small wheel base.* This may be accepted as

proved, and is the one great merit of the Fairlie system; but it is not altogether peculiar to it; the Giovi pattern possesses it to a very considerable degree, and might be so arranged as to be equally efficacious.

*Fifth.—Mr. Fairlie claims that he puts much less weight upon each wheel than ordinary builders.* This he *may* be able to do; but his efforts have not been very successful as yet. Witness the following facts.

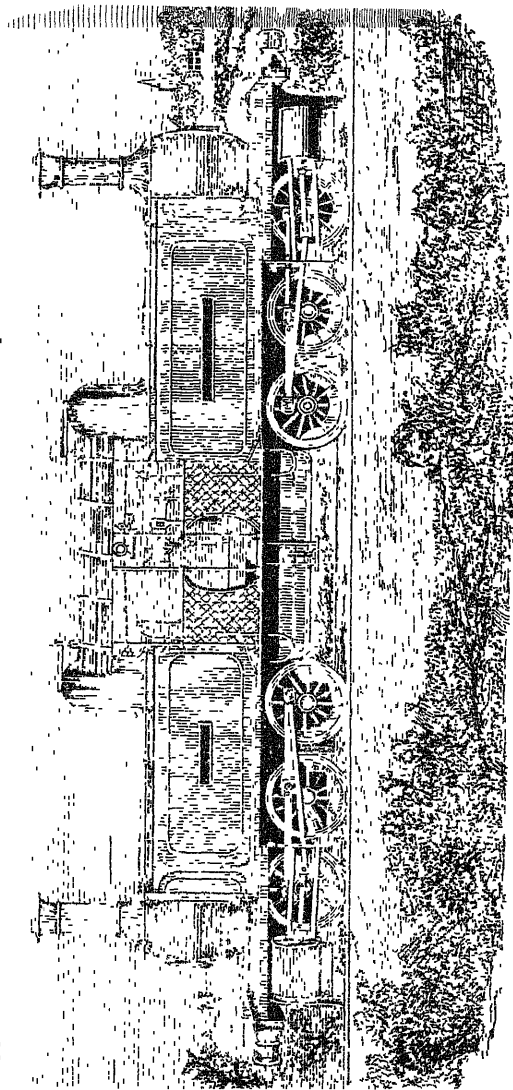
| *Broad gauge.* | *Tons.* | *Narrow gauge.* | *Tons.* |
|---|---|---|---|
| Semmering, .. | 6·45 per wheel. | Welsh Pony, .. | 2·50 per wheel. |
| Giovi, .. | 6 90 " " | Brœlthal, .. | 2·08 " " |
| Mauritius, .. | 6·00 " " | Tongoi, .. | 2·50 " " |
| Bhore Ghât, .. | 6·12 " " | Little Wonder, .. | 2·44 " " |
| Progress, .. | 6·75 " " | | |

*Sixth.—Economy of fuel.* This is opposed to reason; and cannot be accepted without positive proof; which, at present, is not forthcoming.

It is clear that the Fairlie system does not possess one single advantage peculiar to itself or which is not shared by some one of the old patterns. We can, therefore, estimate at its real value the inventor's last and most startling assertion that, for a 3 feet gauge, he is able to construct a locomotive "which shall equal in power the largest engine in use on the 4-8½ gauge." It cannot be supposed that the words "*in use*" are meant to limit the challenge to engines *now in existence.* Such a challenge would be a practical test of his invention; and it must, therefore, be assumed that his meaning is that, on the smaller gauge, he can build a more powerful engine than any that can be constructed on the present system for the broader gauge.

It is difficult to see how he is to effect this, as a recapitulation of the various points in his invention will show.

He obtains tractive power (*a*) by increasing the number of cylinders; (*b*) by a corresponding increase in heating surface; and (*c*) by using a higher steam pressure than usual. As regards the first, the Giovi pattern, (which is older than the Fairlie patent,) already uses four cylinders; and as Mr. Stephenson, many years ago, built and worked successfully a three-cylinder locomotive, a Giovi engine with 6, or even 8, cylinders, can easily be produced. Mr. Fairlie can do no more than this; and if, to gain power, he increases the size of his cylinders, the broad gauge builder

# THE FAIRLIE ENGINE "TARAPACA."

| | ft. | in. |
|---|---|---|
| Number of cylinders, ... ... Four | | |
| Diameter of cylinders, ... ... ... | 1 | 3 |
| Stroke, ... ... ... ... ... ... | 1 | 8 |
| Distance apart of centres of cylinders, ... | 6 | 4½ |
| Distance between centres of valve spindles, | 2 | 11½ |
| " " " motions, | 2 | 9 |
| Distance of centre line of exhaust port from centre of driving axle, .. ... | 10 | 8 |
| Inclination of cylinders, ... 1 in 32 | | |
| Length of steam and exhaust ports, ... | 1 | 2 |
| Width of steam ports, ... ... ... | 0 | 1¼ |
| " exhaust " ... ... ... ... | 0 | 2½ |
| Lap of valve, ... ... ... ... ... | 0 | 1 |
| Travel of valve in full gear, ... ... | 0 | 4½ |
| Length of connecting rods between centres, ... ... ... ... ... | 7 | 3 |

| | ft. | in. |
|---|---|---|
| Transverse distance between centres of coupling rods, ... ... ... ... | 5 | 8 |
| Diameter of wheels, ... ... ... ... | 3 | 6 |
| Wheel base of each bogie, ... ... ... | 7 | 8 |
| Total wheel base, ... ... ... ... | 27 | 11 |
| Distance between centres of bogie pins, ... | 20 | 3 |
| Total length of each bogie frame,... ... | 14 | 5 |
| Total length of engine over buffer beams, | 38 | 9 |
| Transverse distance between bogie frames, | 4 | 1½ |
| " " carrier frames, | 4 | 1 |
| Distance between centres of axle bearings, | 3 | 9½ |
| Diameter of axle bearings, ... ... | 0 | 6 |
| Length " " ... ... ... | 0 | 8 |
| Diameter of boiler barrels inside largest plates, ... ... ... ... ... | 3 | 10 |
| Length of each boiler barrel, ... ... | 10 | 5 |
| " tubes, ... ... ... ... | 10 | 9½ |

| | ft. | in. |
|---|---|---|
| Number of tubes in each barrel, 130 | | |
| Length of fire-box casing, ... ... ... | 8 | 0 |
| Total length of boiler between smoke box tube plates, ... ... .. ... | 29 | 0 |
| Height of fire-box casing, ... ... ... | 6 | 4½ |
| Width of fire-box casing at ends, ... ... | 3 | 10 |
| " centre, ... | 3 | 0 |
| *Heating surface.* square feet. | | |
| Fire-boxes, ... ... 125 | | |
| Tubes, ... ... ... 1500 | | |
| Total, ... 1625 | | |
| Firegrate area ... ... 21 | | |
| Contents of tanks ... 2200 gallons. | | |
| Weight in working order 60 tons equally distributed. | | |

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can do the same. As regards the second point: the Giovi pattern has also the enlarged grate and double set of tubes, and these can be lengthened or enlarged in the same proportion as in the Fairlie engine. Lastly, the broad gauge builder can use steam of as high pressure as Mr. Fairlie; especially if, like him, he makes his boiler of steel.

Thus, whatever facilities Mr. Fairlie possesses, are equally available to other builders; so that, on the same gauge, engines of equal power and capability can be constructed on either system. It stands to reason therefore that, where the gauges differ, the engine constructed for the broader one ought, and must necessarily be, the more powerful of the two; inasmuch as the boiler capacity must be *à priori* larger, owing to its greater width; whilst it is more capable of being conveniently expanded both vertically and laterally to a much greater proportionate extent than on the smaller gauge.

Whilst therefore Mr. Fairlie's locomotive shares in the advantages possessed by all bogie engines, of freedom from oscillation and consequent injury to the permanent way, his assertions with regard to its superior power and economy must be received with caution. He has not yet put them to any practical proof, and reason and experience are alike opposed to them.

SIMLA,<br>
15*th Sept.*, 1870. C. C.

*P.S.*—Since writing the above, the "*Engineer*" of August 26th has come to hand, containing a description of the Tarapacá engine just completed; which is pronounced by the Editor the *ne plus ultra* of the Fairlie system. I have added the details of her machinery and estimated performances at the end of the table. The latter it must be remembered are mere estimates and not *boná fide* performances, and they do not indicate any advance on Mr. Fairlie's part. Whilst more powerful than the "Progress," she is very little stronger than the "Little Wonder," and much inferior to the first seven on the list. Her intended cylinder pressure is higher than any yet recorded, and is nearly double that of ordinary locomotives. Although the Tarapacá is mounted on six-wheeled bogies, thereby increasing the wheel base from 5 feet (as in the "Progress" and "Mountaineer") to 7½ feet, the weight per wheel is still nearly 5 tons; she thus in no way invalidates, but on the contrary confirms, the conclusions arrived at in this note.

TABLE SHOWING COMPARATIVE PERFORMANCES OF THE FAIRLIE AND OTHER ENGINES.

| Name of engine or line on which employed. | Weight. | Gauge of line. | Wheels. | | | Heating surface. | | Cylinders. | | | | Results by actual experiment. | | | | | | | Relative power. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | Steam pressure. | | Tractive force. | | | |
| | | | Total number. | Number coupled. | Diameter of drivers. | Grate area. | Total. | Number. | Diameter. | Stroke. | Total area of pistons (both sides). | Gradient. | Speed per hour. | Load. | Boiler. | Cylinder. | Total. | Per square inch of piston area. | lbs per square inch of piston per each lb. of pressure. | Semmering = 1000. |
| | tons. | ft. in. | no. | no. | ft. in. | s. ft. | s. ft. | no. | ins. | ins. | sq. ins. | | ms. | tons. | lbs. | lbs. | lbs. | lbs | lbs. | |
| Little Wonder (Fairlie), ... | $19\frac{1}{4}$ | $1–11\frac{1}{2}$ | 8 | all | 2–4 | 11·00 | 730 | 4 | $8\frac{3}{16}$ | 13 | 421 2 | $\frac{1}{92}$ | $14\frac{1}{2}$ | $94\frac{1}{2}$ | 150 | 55 | 3450 | 8 2 | 0·149 | |
| | | | | | | | | | | | | $\frac{1}{92}$ | $11\frac{1}{4}$ | $141\frac{1}{4}$ | 175 | $81\frac{1}{4}$ | 5076 | 12 0 | 0·147 | |
| | | | | | | | | | | | | $\frac{1}{85}$ | 5 | 206 | 170 | 125 | 7760 | 18 4 | 0·147 | |
| | | | | | | | | | | | | $\frac{1}{92}$ | 13 | $114\frac{3}{4}$ | 135 to 170 | 67 | 4170 | 9 9 | 0·148 | |
| | | | | | | | | | | | | | | | | | Average, | | 0·148 | 813 |
| Welsh Pony, ... ... ... | 10 | $1–11\frac{1}{2}$ | 4 | all | 2–0 | ... | ... | 2 | $8\frac{1}{8}$ | 12 | 207 4 | $\frac{1}{85}$ | 5 | $73\frac{3}{4}$ | 150 | 84 | 2778 | 13 4 | 0·159 | 874 |
| Brœlthal railway, ... ... | $12\frac{1}{2}$ | 2–7 | 6 | all | $2–3\frac{1}{4}$ | 4 25 | 174 | 2 | $10\frac{13}{16}$ | 10 | 367·2 | L | 9 | $282\frac{1}{2}$ | 90 | 76 | 3248 | 8 9 | 0 117 | 643 |
| Norwegian railways, ... | 14 | 3–6 | 6 | 4 | 3–0 | ... | 400 | 2 | 10 | 18 | 314·2 | $\frac{1}{25}$ | 15 | $66\frac{1}{2}$ | 120 | $73\frac{1}{2}$ | 3676 | 11 7 | 0·158 | 868 |
| Swedish railways, ... .. | 17 | 3–6 | 6 | 4 | 3–9 | ... | ... | 2 | 11 | 18 | 380 0 | $\frac{1}{118}$ | 14 | 149 | 110 | 96 | 4634 | 12·2 | 0 123 | |
| | | | | | | | | | | | | $\frac{1}{100}$ | 10 | 149 | 110 | 105 | 5066 | 13·3 | 0·127 | |
| | | | | | | | | | | | | | | | | | Average, | | 0·125 | 687 |
| Tongoi railways, Chili, ... | 15 | 3–6 | 6 | all | 2–6 | 5·75 | ... | 2 | 12 | 17 | 452·0 | $\frac{1}{129}$ | 9 | 120 | ... | $43\frac{1}{2}$ | 3540 | 7 8 | 0 180 | |
| Carrigal railways, Chili, ... | 15 | 4–2 | | | | | | | | | | $\frac{1}{25}$ | 5 | 52 | ... | 58 | 4740 | 10·5 | 0·181 | |
| | | | | | | | | | | | | | | | | | Average, | | $0·180\frac{1}{2}$ | 992 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Semmering, ... ... ... | 55¼ | 4-8½ | 8 | 6 | 3-7¾ | 12·60 | 1,660 | 2 | 18·7 | 24 | 1098·6 | $\frac{1}{40}$ | 11¼ | 165¼ | ... | 56 | 11,204 | 10 2 | 0·182 | 1000 |
| Giovi incline, ... ... ... | 55¼ | 4-8½ | 8 | all | 3-6 | ... | ... | 4 | 14 | 22 | 1231·2 | $\frac{1}{36}$ | 15 | 155 | ... | 56 | 11,548 | 9 4 | 0·168 | 923 |
| Progress (Fairlie), ... ... | 54 | 4-8½ | 8 | a l | 4-6 | 19·50 | 1,993 | 4 | 15 | 22 | 1413 6 | $\frac{1}{90}$ | 8 | 530 | 140 | 105 | 19,292 | 13·6 | 0·130 | |
| | | | | | | | | | | | | $\frac{1}{39}$ | 7 | 206 | 130 | 77 | 14,070 | 9·9 | 0 129 | |
| | | | | | | | | | | | | $\frac{1}{180}$ | 15 | 754 | ... | 102 | 18,700 | 13 2 | 0·130 | |
| | | | | | | | | | | | | | | | | | Average, | | 0·129⅔ | 712 |
| Mauritius railway, ... ... | 48 | 4-8½ | 8 | all | 4-0 | ... | ... | 2 | 18 | 24 | 1017 6 | $\frac{1}{27}$ | 9 | 148 | 120 | 86 | 13,986 | 13 7 | 0 159 | |
| | | | | | | | | | | | | $\frac{1}{46 6}$ | 11 | 131 | ... | 48 | 7,820 | 7 7 | 0·160 | |
| | | | | | | | | | | | | | | | | | Average, | | 0 159½ | 876 |
| Bhore Ghât, ... ... ... | 49 | 5-6 | 8 | all | 4-0 | ... | ... | 2 | 18 | 24 | 1017 6 | L | 0⅝ | 600 | 120 | 40 | 6,600 | 6 5 | 0 162 | |
| | | | | | | | | | | | | $\frac{1}{48}$ | 10 | 160 | 140 | 57 | 9,280 | 9 1 | 0 160 | |
| | | | | | | | | | | | | $\frac{1}{37}$ | 10 | 160 | 140 | 71 | 11,520 | 11 3 | 0 160 | |
| | | | | | | | | | | | | | | | | | Average, | | 0·160⅔ | 883 |
| Valparaiso and Santiago line (passenger), ... ... | 20 | 5-6 | 6 | 4 | 5-0 | 13·12 | 922 | 2 | 15 | 22 | 706·8 | $\frac{1}{44}$ | 10 | 112 | 110 | 85 | 7,000 | 10 0 | 0 118 | |
| | | | | | | | | | | | | $\frac{1}{55}$ | 10 | 134½ | 110 | 85 | 7,062 | 10·0 | 0·118 | |
| | | | | | | | | | | | | | | | | | Average, | | 0·118 | 648 |
| Do. do. (goods),... ... ... | 27 | 5-6 | 6 | 4 | 4-6 | 13·12 | 1,094 | 2 | 16⅓ | 24 | 855·2 | $\frac{1}{50}$ | 10 | 203⅓ | 120 | 94 | 11,386 | 13 3 | 0·141 | 774 |

ADDITIONAL.

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tarapacá (Fairlie), ... ... | 58 | 4-8½ | 12 | all | 3-6 | 21·00 | 1,646 | 4 | 15 | 20 | 1413·6 | ... | ... | ... | ... | 100 | 21,280 | 15·0 | 0·150 | 824 |

## No. CCXCIV.

## NOTE ON ARTIFICIAL CEMENTS.

*Report on the means and advisability of manufacturing Artificial Hydraulic Cements in the North-Western Provinces of India.* By LIEUT.-COL. H. A. BROWNLOW, R.E.

THE cements principally used for building purposes in England may be divided into two classes—the natural and artificial.

The natural or "Roman" cements are obtained from nodules of argillaceous lime-stone, chiefly found in the clay strata, which alternate with lime-stone beds of the Oolite formation, in the clay-overlying chalk and in the London clay. Though sometimes obtained by digging, they are generally gathered on the sea-shore after storms and high tides. The stone is burnt in open kilns to an extent sufficient to drive off the carbonic acid, and the cement is then ground and packed for use.

The burnt Roman cement weighs about 80 lbs. per bushel; its resistance to compression when 40 days old, varies from 850 to 1,200 lbs. per square inch, and its tenacity is about 90 lbs. per square inch; the specimens in the latter case having been allowed to remain seven days under water after having been made up.

The artificial or "Portland" cements consist of chalk and clay, mixed in certain definite proportions, and burnt at a very high temperature. The raw ingredients are first "washed," *i. e.*, mixed intimately together with water under harrows revolving in vats about four feet deep. The mixture is gradually allowed to run off through fine sieves into reservoirs, from which, after attaining the consistency of stiff paste, it is removed to drying floors; on these it is baked until thoroughly dry, and it is then removed, as dug out in rough blocks, to the kilns.

These are loaded with alternate layers of coke and raw cement, and the burning is carried on to a point apparently just short of that necessary to produce vitrification. The clinker or unground cement, is then crushed between iron rollers, finely ground between horizontal mill-stones, and packed for use. The ground cement should properly be spread out, and allowed to cool from some days on a dry floor before it is packed, as this "air slaking" (perhaps by killing any particles of pure lime which remain in an active state) is most beneficial to it. But it is doubtful whether this is always done.

The pulverised cement weighs about 112 lbs. per bushel: its resistance to compression when 40 days old is 2,450 lbs. per square inch, and its tenacity, after having been allowed to set seven days under water, between 300 lbs. and 350 lbs. per square inch.

A comparison of the figures with those given above, will show the marked superiority of the Portland over the Roman cement in the important points of tenacity and resistance to compression.

Roman cement has the solitary advantage of setting quicker than the Portland: indeed, when concrete made of the latter is used under water, great care must be exercised at first in checking any current, either natural or caused by pumping, or the cement may be carried away leaving only the clean gravel. Bnt having taken this precaution, Portland cement is, undoubtedly, admirably adapted for use in hydraulic works. It sets harder under still water than it does in air, and would, as far as I can judge, stand the action of any current after having been allowed two days to set. If kept dry in casks, it rather improves by age; whereas Roman cement loses its strength considerably. It has three times the strength of Roman cement, and will safely bear an admixture of three to four equal volumes of clean sharp sand, for which mixture Roman cement is very ill-adapted. Salt water is as good for mixing with it as fresh. Portland cement concrete, made in the proportion of one of cement to two of clean sharp sand, and five of gravel, can be used with the most perfect success for sea and river walls, foundations, &c. At Brest, the French Engineers make blocks of masonry 16·5 feet in length, 10 feet in breadth, and 10 feet in width of rough stone, set in mortar consisting of one part of Portland cement to three and a half parts of sand. These blocks, made on land, are launched into the water, and allowed to set for three weeks after which they can be raised by floats, and laid in positions exposed to

the full action of the sea without any fear of rupture. In Dublin, concrete blocks were formed of one part of Portland cement to six parts of gravel, measuring 26 by 23 feet by 10 feet, and weighing 330 tons each.

There can be no doubt, therefore, of the entire applicability of it, or of a cement like it, to our hydraulic works in India, whether employed in construction and repair of Falls on the canals, or in concrete blocks for Dams across the rivers. As far as the raw material is concerned, too, there is no lack of pure rich lime and of clay in the country. The question, therefore, now, arises for consideration,—Is it cheaper to import or to manufacture in India?

Portland cement of the very first qualities can be delivered by the manufacturers free on board vessels in the Thames at 10*s.* per cask, containing 400 lbs. net of cement. The freight to India in vessels sailing round the Cape, and landing charges in India, should not exceed 6*s.* per cask. The Railway charge per cask from Calcutta to Delhi would be Rs. 14·66, at ½ pie per maund per mile. Therefore, the cost of 400 lbs. net of first class English made cement at Delhi would be Rs. 22·66, say Rs. 23 to cover losses. 400 lbs. weight, at 42 lbs. per bushel of 1·28 cubic feet capacity, being equal to 4·5 cubic feet, we may take the cost of a cubic foot of English cement at Delhi to be Rs. 5-2.*

As at present informed, I do not think we can manufacture a cement possessing the extraordinary tenacity of the Portland in India. Some action, not very clearly understood, appears to take place during the burning, between the oxide of iron contained in the clay and the particles of chalk, just before the lime in the latter becomes caustic. We should, I think, find it advantageous in other respects to substitute pure slaked lime for chalk. And the subject is such a difficult one that it would be very unsafe to predicate theoretically the results of any departure from

* When it may be necessary to import Portland cement into India, the specification for quality should be as follows :—

"The whole to be of the very best quality, ground extremely fine, weighing not less than 112 lbs. to the striked bushel, and capable of maintaining a breaking weight of 750 lbs. on an area of 1½ inches square or 2¼ square inches, seven days after having been made in an iron mould, the cement having been immersed in water during the seven days." It should be packed in fir casks with staves not less than half inch thick, each cask having four iron hoops, and being lined with water-proof brown paper The casks should be of manageable size and weight, so as to avoid needless knocking about in stowing and transit. A larger quantity than 400 lbs. net should not be packed in any one cask, and perhaps 300 lbs. would be a better quantity where cement is intended to go far inland. I may add that it would be very much better to get it from some of the well-known makers (such as Knight, Bevan & Co., J. B. White & Co., Robins & Co., Hilton, Anderson & Co.), paying a fair price for it, than to go into the market for the cheapest article. Inferior cement of uncertain quality would be worse than the hydraulic mortar we already have in India

a known process. An instance came to my notice, during my late inquiries on the subject, in which the strength of a manufacturer's cement fell suddenly to one-half of proof strength, for no other ascertainable cause than increased rapidity of "washing." I am somewhat doubtful, too, about our being able to produce economically the very high degree of heat required for burning the Portland cements.

An extended series of experiments conducted by Mr. John Grant, C.E., show that Portland cement mixed with two parts of sand is half the strength of neat cement; mixed with three parts of sand, the strength is one-third of neat cement. If, therefore, we can produce a cement of one-third of the tenacity of Portland cement, we must clearly do so at a cost something less than one-fourth of the cost of the Portland, or it will not pay us to incur the risk of manufacture. For, the volumes being equal, the Portland cement will make four times as much mortar of the same tenacity as the cement of Indian manufacture. Similarly, we can only afford to pay one-third of the cost of Portland for a cement of half its tenacity.

Roughly, I should estimate the cost of manufacturing a cement in India at about one Rupee per cubic foot. For every 400 lbs. net of cement, we should require about $1\frac{3}{4}$ maunds of pure lime, costing 7 annas, and $3\frac{1}{2}$ maunds of good clay, for the excavation and carriage of which $\frac{1}{2}$ an anna would be an ample allowance. The cost of actual manufacture is not likely to be less than it is in England, where the operations are conducted with the greatest regard to economy, and under the most favorable circumstances. Now, at all the factories on the Thames and Medway, the chalk is dug on the premises, costing merely a nominal sum, and the clay is brought from the alluvial flats in the river at a cost of 1*s.* 6*d.* a ton, while competition has cut down the profits on manufacture to a very low margin. If, therefore, we deduct from the cost of

| | Shillings. |
|---|---|
| a 400 lbs. cask, .. ... ... ... ... ... ... ... | 10 |
| Estimated cost of cask, ... ... ... ... ... ... ... ... | 3 |
| 10 per cent. manufacturer's profit, ... ... ... ... | 1 |
| Cost of fuel at 6*s.* per ton of cement, ... ... ... ... | 1 |
| 20 per cent. wear and tear of machinery and other expenses, that would not perhaps be incurred in India, | 2 |
| | 7 |

The balance, three shillings, may not unreasonably be taken as the actual cost of manufacturing 400 lbs. net of cement. The cost of making cement in India might then be estimated as follows :—

| | | RS. | A. |
|---|---|---|---|
| Raw material, | ... ... ... ... | 0 | 7½ |
| Fuel (see below), | ... ... ... ... | 3 | 8 |
| Cost of making, | ... ... ... ... | 1 | 8½ |
| | Total, ... | 5 | 8 |

for 400 lbs., or six cubic feet; supposing its density to be about the same as that of Roman cement. The cost of a cubic foot would then be about one rupee, or one-fifth that of neat Portland cement of first quality.

I would, therefore, suggest that a number of samples should be made up in India of cements formed of the hydrate of pure rich lime, mixed with various clays within the limits of the proportions laid down below. The samples, when burnt, should be finely pulverised, and, when cool, should be moulded into bricks of the form shown by shaded portion of marginal diagram. There should be at least a dozen bricks of each sample, and they should be allowed to set under still water for seven days after they have been taken out of the moulds. The lower of the two iron clips shown in the diagram should then be loaded until the bricks are torn in two, and if any of the samples prove themselves capable of supporting an average weight of 225 to 250 lbs. on the area 1½ inch square (or 2¼ square inches), I think we may safely adventure upon the manufacture. I have been particular in giving dimensions of the sample brick, as I wish to adhere as exactly as possible to the form of test generally used in England. It would be instructive and interesting to make up and treat in the same way bricks of the best "kunkur" lime.*

Thickness of brick = 1¼ inches

* The accompanying comparison of analysis of the English "septaria," which furnish the quick setting Roman cement and of the nodular kunkur of India, shows that the latter has lime in excess and a deficiency of clay—

| | | English Septaria. | Nodular kunkur. |
|---|---|---|---|
| Carbonate of lime, | ... ... ... ... ... | 65 80 | 72·00 |
| Silica, ... | ... ... ... ... ... ... | 18·00 | 25·20 |
| Alumina and oxide of iron, | ... ... ... ... | 12·60 | 11·00 |
| Water, &c, | ... ... ... ... ... ... | 3·60 | 1 80 |
| | Total, ... | 100·00 | 100·00 |

Supposing it be decided to commence manufacturing in India, I think we should aim first at the utmost simplicity in the machinery and plant employed. If we commence work with a number of expensive English-made machines (admirably adapted for use in England owing to the high price of labor and facilities of repair), we shall soon find them get out of order, find repairs expensively and slowly executed, and most probably find ourselves turning out an inferior article at a higher price than that at which we could have imported the best English cement. Whereas, with simple machinery, easily made and repaired in the country, we shall go on gaining experience of work on the large scale, and can either abandon, or extend and improve, our operations, as may seem advisable, at a minimum outlay. We must now consider the questions of raw material, fuel, site of factory, and process of manufacture.

I think that the pure rich lime of the lower Himalayan ranges would be the best substitute for chalk. Practically, it is chalk with the carbonic acid driven off, and by its use we should save much wear and tear in grinding and mixing it with the clay. The harder lime-stones would require stone-crushers and extremely hard mill-stones to pulverise them.

A German analysis gives the following as the composition of the Medway clay, which is used in the manufacture of most of the London cement :—

| | |
|---|---|
| Silica, ... ... ... ... ... ... | 68·45 |
| Alumina, ... ... ... ... ... | 11·64 |
| Oxide of iron, ... ... ... ... ... | 14·80 |
| Soda and potash, ... ... ... ... | 4 00 |
| Carb. lime and loss, ... ... ... ... | 1·11 |
| | 100 00 |

Dr. Ure says, that " all good hydraulic mortars must contain alumina and silica, the oxides of iron and manganese, at one time considered essential, are rather prejudicial ingredients." Vicat is of opinion that the peroxide of iron exerts an injurious influence upon hydraulic mortars. M. Lipowitz, a German writer on the subject, whose treatise has been translated by Mr. Reid, quotes, with approval, an opinion " that the

As the rich lime delays, and alumina quickens, the setting, it would be well worth while trying the effect of mixing up kunkur lime with solutions of alum (sulphate of alumina) of various degrees of strength. If we can thereby obtain a quicker and harder setting mortar, there are many cases in which it would well repay us to incur the extra expense for portions of a work liable to severe action of water. Bricks made of the lime thus treated should be tested in the same way as those of artificial cement.

best clays for cements are those which contain iron up to 10 or 15 per cent. in the form of iron oxydule." General Gillmore says, that the clays most suitable for combination with common slaked lime for preparation of artificial cement contain 30 to 50 per cent. of alumina and 4 to 5 per cent. of carbonate of lime. He considers that the oxides of iron do not confer hydraulic activity, whatever may be their action at subsequent stages of the induration. If we wish to produce a compound silicate of alumina and lime, which is, according to some, all that is necessary, we must have the following proportions :—

| | | | | Per cent. | |
|---|---|---|---|---|---|
| Lime | 2 chemical equivalents | = 57 × 2 | = 114·0 | 28·3 | |
| Silica | 2 ,, ,, | = 93 × 2 | = 186·0 | 46 2 | 64·5 |
| Alumina | 1 ,, ,, | | = 102·8 | 25·5 | 35·5 |
| | | | 402·8 | 100·0 | 100·0 |

The best analysis of Portland cement gives—

| | | |
|---|---|---|
| Lime | 60 | per cent. |
| Silica | 23 to 20 | ,, |
| Alumina | 7 to 10 | ,, |
| Oxide of iron | 5 to 1 | ,, |
| Alkalies, carb. acid and water, | 5 to 9 | per cent. |

15 per cent. of the oxides of iron in the raw clay would give about 4 per cent. in the burnt cement. I think, therefore, that the clay should, if possible, contain oxides of iron, in any proportion up to 15 per cent.; but that, if this cannot be secured, any *compact greasy clay free from sand* will answer our purpose, although, perhaps, not quite so well as the other. The proportion of pure lime added can always be modified according to the chemical composition of the clay used.

All the persons engaged in the manufacture of cement, whom I consulted on the subject, were most positive in their assertion that it could only be burnt with coke. The flare of coal or wood, they said, would at once virtrify and ruin a kiln. From which I infer that it requires a strong, steady, condensed heat, if I may use the phrase. Charcoal ought to do as well as coke, and perhaps the dried cakes of cow-dung so universally used for lime-burning in the plains of India might answer the purpose also. I cannot say exactly what would be the price of coke at Delhi; but taking losses by the way into consideration, I should think that it would cost us fully Rs. 2 per maund; charcoal would perhaps not cost us more than 10 annas a maund, if made for the factory on a large scale; and in calculating the probable cost of manufacturing cement in India,

I have assumed that it would be used at the rate of 30 maunds to a ton of cement. I get at this rate by supposing that charcoal has, weight for weight, $\frac{1}{3}$rd of the heating power of coke. The English rate of consumption is, as far as I can learn, $\frac{7}{10}$ths of a chaldron of coke per ton of cement, and a chaldron weighs about half a ton. Therefore $3 \times \frac{7}{10} \times \frac{1}{2} \times 28$ maunds $= 29{\cdot}4$ maunds, say 30 maunds will be the weight of charcoal required.

In establishing a manufactory for the North-Western Provinces of India, the selection of site would be determined by considerations of—

1*st*. Accessibility to raw materials and fuel.

2*ndly*. Possibility of obtaining cheap motive power.

3*rdly*. Cheap conveyance for manufactured article.

I think that one of the Falls on the Ganges Canal in the neighbourhood of the Railway between Delhi and Meerut, (either Bhola or Dasna,) would be found to fulfil the above conditions more completely than any other place. We should have water carriage down the canal for the lime, clay, and fuel: super-abundant water-power, and conveyance both by rail and canal for the manufactured cement.

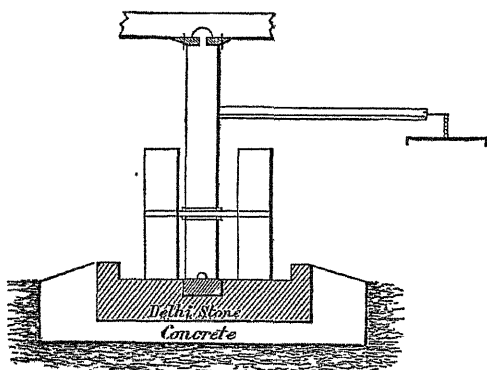
M. Lipowitz objects to the "washing" process adopted by English manufacturers of cement, on the grounds of its producing a comparatively imperfect mixture, and draining away certain valuable constituents of the raw cement which are soluble in water. From what I saw myself, I am fully convinced that unequal settlement must take place in the drying reservoirs; the coarser and denser particles of the mixture falling towards the bottom and entrance, while the finer and lighter remain at the top, and pass on to the remoter corners. He also says, that "if clay containing silica or iron is mixed with caustic lime, with the addition of cold water, and then dried, a much less intimate mixture is formed than if the water were heated to 100° Centigrade. If the two mixtures, with hot and cold water, are burned and treated in the same way, there is a perceptible difference in the quality of the cement. This difference is still greater if $\frac{3}{4}$ to 2 per cent. of calcined soda is added to the hot water, and the bricks are dried by artificial means. The cement must be mixed with from 30 to 35 per cent. of water." In the general outline of manufacturing process proposed in the succeeding paragraph, I have followed very closely the suggestions of M. Lipowitz, who has evidently a thorough knowledge of his subject.

*(a)*.—The lime and the clay which it is proposed to mix must be first *thoroughly dried* in the sun, but the clay should be used as fresh as possible, and any exposure of it to sun and air, further than that absolutely necessary to dry it, should be carefully avoided.

*(b)*.—The material must then be separately pounded, either by hand or any simple machine, into pieces not larger than a pea, and the pounded materials should be screened so as to ensure the exclusion of coarse lumps.

The pounded materials should then be passed in certain definite proportions through a hopper between a pair of ordinary flour mill-stones adjusted so as to grind them as fine as flour. It will save much wear and tear and do the work more thoroughly, if the materials are passed through two pair of stones in succession, the first pair adjusted to grind more coarsely than the second.

*(c)*.—The exact proportions of lime and clay to be employed will depend upon the chemical constituents of the materials used, and must be fixed on the spot. Generally speaking, there should not be less than 40, or more than 60, per cent. of pure lime, and from 60 to 40 per cent. of clay. Having been fixed, the proportions must be most carefully adhered to, as any carelessness in this matter will of course vitiate all future operations.

*(d)*.—The pulverised material should then be mixed in a cylindrical vat with a graduated scale on its side, in the proportion of thirty volumes of powder to ten of *boiling* water, in which has been mixed $\frac{1}{4}$th volume of calcined soda and $\frac{1}{2}$ lb. of freshly-burnt and slaked lime.

*(e)*.—From the vat, remove the mixture to a basin in which a couple of mill-stones should be made to revolve on their edges round a vertical shaft, as in the case of a steam mortar mill. The basin should be only just large enough for the stones to revolve in, should be carefully and smoothly paved with hard stone, and should be surrounded by a rim of wood

or masonry 8 inches to 12 inches high. The stones should be fixed at slightly unequal distances from the vertical shaft, so as not to run exactly in each other's tracks, and at the outset I should think it would amply suffice to move them by animal power as shown in sketch. They could afterwards be easily connected with the water wheel that drives the mills.

*(f)*.—From the edge runners, the mixture should be taken to a pug-mill, and, when thoroughly pugged, should be cut off in small bricks or lumps, not exceeding 2 inches or 2½ inches in thickness, as it comes out of a shoot fixed at bottom of mill.

*(g)*.—It may not be amiss to remark here that too much pains cannot be bestowed on the thorough incorporation of the raw materials, and in keeping them clean and free from sand and foreign ingredients during the process. As far as any chemical action is concerned, the clay remains almost inert after the mixture has attained a dull red heat, so that it is most important to bring it into the closest contact with the lime before the burning commences. The presence of sand tends to produce vitrifaction during burning, and is most prejudicial to the cement.

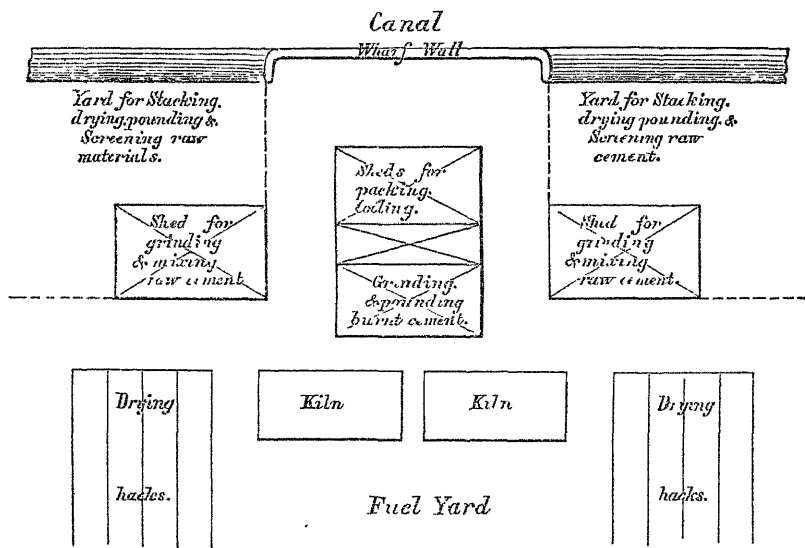
*(h)*.—M. Lipowitz objects to drying in the air, and quotes two examples where doing so was found to be most injurious to the cement. But the English manufacturers expose their raw cement freely to the air in the reservoirs, where it sometimes lies for a couple of months before it is burned; and in one factory, I saw it being wheeled direct from the drying reservoirs to the kilns. So that, until experience shows us in India that kiln-dried, is stronger than sun-dried, cement, I should recommend stacking the blocks of raw cement, as removed from the pug-mill, in drying hacks like bricks.

*(i)*.—When *thoroughly* dry, the blocks of raw cement should be burned, either in clamps with dried cow-dung, or in a good lime kiln with thoroughly dry wood, or with charcoal, as experience on the spot may show to be most advantageous.

*(k)*.—The burnt cement should then be pounded until it can pass through a screen with meshes the size of a pea, and finally be ground as fine as flour. It should then be allowed to cool thoroughly on a dry floor.

*(l)*.—The cheapest packing for India would be in bags or sacks. These would not have any sea voyage to undergo, and the cement would, in all

probability, be used tolerably fresh. Where it had to be sent long distances, small barrels could doubtless be purchased at advantageous rates from the nearest commissariat depôt.

In the foregoing paragraph, I have written very much that is well known to all who have studied the subject of cements; but as it is the result of a good deal of reading and seeing, and subsequent thought on my own part, I have thought it best to say my say in full. The samples mentioned above should be carefully made up in the manner already laid down, accurately labelled and tested. The strongest composition having been thus ascertained, steady and persevering efforts at economical production must be made. I am most strongly convinced of the good policy of beginning in the simplest manner, consistent with economy and efficiency. Mistakes can then be easily and inexpensively rectified. The site of the factory should, from the very first, be laid out with an eye to expansion of business, and economical working on a large scale. There should be no carrying backwards and forwards, the general arrangement of the works being somewhat as indicated below.

As regards the supervision of manufacture, I regret to say that I have, after much inquiry, been quite unable to hear of any person likely to answer the requirements of the Government of India. The difficulties of

manufacture lie in the thorough incorporation and proper burning of the ingredients. The correct proportioning of them depends upon their chemical constitution, and the foremen of manufactories on the Thames and Medway, although well acquainted with the mechanical process, evidently know nothing of the chemistry of the subject. They work with well known materials by rule of thumb, and would be all abroad when thrown in contact with new materials. Besides, they are valuable men to their employers, and an attempt to secure the services of any one of them by offers of higher pay, could only be made through his employer, with prospects of success that may easily be imagined. After all, the qualitative and quantitative examinations of lime-stone and clay, necessary for our purpose, are neither very elaborate, nor do they require any profound knowledge of chemistry. Attention and experience will overcome difficulties of manufacture in a very short time, while experiment alone can determine the exact proportions of the raw materials most suitable to any new locality. So that we might obtain the services of a picked intelligent Non-Commissioned Officer of Royal Engineers, have him trained in the chemical part of the subject at the Government School of Mines, and send him out to work under an Engineer Officer in India. But for the war, I should have suggested an attempt to secure the services of a German, with both the chemical and practical knowledge necessary for our purposes, as I know that there are cement factories in Prussia conducted on the very best principles. I have heard that there are factories in Holland also; if so, a man might be found ready to our hand there. Of one thing, however, I am certain, which is, that if it be at any time decided to start the manufacture of cement in India, we must either get a person for its general supervision considerably above the ordinary run of the Upper Subordinate Grade in India, or must send out an Upper Subordinate to work under an Engineer out there. Every factory in this country has a Manager over the Foreman, with a thorough knowledge of machinery, construction, &c., as well as of the mere process of manufacture. And if the thing is to prosper, the Superintendent of the factory must be a picked man of skill, energy, and patience, able to devote his whole time to the work. It will not do to take any man that can be laid hold of, or trust to the supervision that can be given in his spare moments by an able but over-worked Executive Engineer, with a large canal or barrack division on his hands as well.

In conclusion, I must add a few words on the manipulation of the manufactured cement, which are, I think, necessary, as it has not been hitherto extensively used in India, and the best cement may be utterly ruined by careless handling on the works. *In the first place, only just so much of it as is required for immediate use should be made up at any one time, as when once it has commenced to harden it cannot be worked up again* like a mortar containing rich lime. In mixing it with sand or gravel, *the ingredients should be well mixed together in a dry state,* before any water is added. In adding the water, only pour in enough to make a stiff paste, as flooding the cement is most prejudicial to it. The sand used should be clean and sharp, and when cement is used in brick-work, *the bricks must be thoroughly saturated in water before use,* otherwise they will absorb the moisture necessary for the proper setting of the cement. When used under water, cement must, until it has set, be protected from any current.

H. A. B.

LONDON,
11*th August*, 1870.

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## No. CCXCV.

# IRON TRAMROADS FOR INDIA.

*By the Editor.*

I WISH to draw attention to a subject, not new in itself, but the importance of which is, I think, very great, and which may be advantageously re-discussed at the present time by the light of recent experience. I allude to the substitution of an Iron Roadway of some kind for the metalling of an ordinary road.

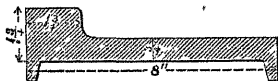
The extension of Roads is almost a necessary corollary to the construction of Railways. Without such extension, only a limited portion of the traffic of the country, whether in passengers or goods, is carried by the railway. The construction of subsidiary or branch *locomotive* lines will doubtless follow in time, but even after that, there will be a considerable number of lines on which it will not pay to work locomotives, and which will be worked, as now, by animal power.

The cost of metalling over a large part of the country is very high. In the Upper Provinces it appears to be yearly increasing—while in Bengal and Burmah, the absence of stone and kunkur necessitates, I believe, the employment of burnt brick, a very inferior and expensive material for the purpose; nor does the moorum, so extensively used in other parts of India, seem any better.

I believe that where this high price and scarcity of material prevail, an iron road may often be economically substituted. What I propose, however, is not a light railway, but a Tram-rail, by which the ordinary vehicles of the country can be served at less cost and with less friction than on a metalled road, and which, at the same time, will give a railway on which vehicles with flanged wheels can run for the transport of goods and passengers, who now go on foot, and who would be as willing to pay for being carried short distances on a road as long distances on an ordinary railway.

It appears to be an established principle, and is perhaps almost a necessity with Locomotive Railways, that their halting stations, however small, should have passenger waiting-rooms, goods sheds, sidings, and other accompaniments; those cost a considerable sum of money, however economically constructed. It appears also to be an established principle that the speed upon a Locomotive Railway, even for a short branch line, whether for the carriage of passengers or goods, must be not less than 20 miles per hour. To attain this average speed there must not be many halting places. The consequence of this, added to the cost of the station, is, that the least possible number of stations are made, and at distances seldom less than ten miles apart, so that the greater portion of the passengers living along the route of the Railway, have to walk or be conveyed at least five miles before they can reach the station. Such is also the case with goods; they must be transported some considerable distance, and have incurred a considerable cost before they arrive at the Railway station. If, however, the Railway could be laid along the existing public roads, and through the inhabited portion of the country; if also the train could stop anywhere along the route and take up a single passenger—the above disadvantages of the Locomotive Railway would be avoided.*

Such a tram-rail as is shown in the diagram is now employed, I understand, for this purpose, in the state of New York† and elsewhere.

I am not sure it is the best pattern for our purpose, but that is a matter of detail if the principle can be justified.

The advantage of such an arrangement I believe to be, that its first cost to Government would often be less than the metalling of an ordinary road, that it would accomodate (without disturbing) the ordi-

* *See* Burn on Horse Railways, p. 11.

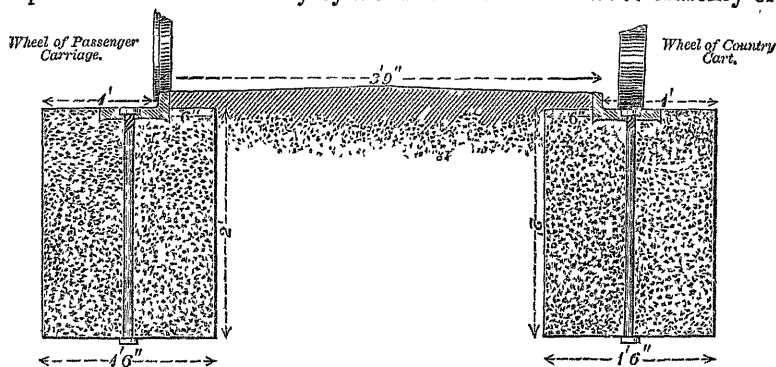
† In the United States they, in many cases, lay down a rail which forms a railway for flanged vehicles, and a tramway for ordinary vehicles,—the form of the rail is that shown in the diagram. The ordinary vehicles not having flanged wheels find this tramway a great advantage; and many of the goods wagon proprietors, and those of public vehicles and private carriages, have the gauge of the wheels made to suit the tramway. Did we not know that the contrary was the case, we should imagine that such a system as a combination of a tram and railway and of slow and fast vehicles could not work harmoniously together, but that the velocity of the slowest vehicle must govern the velocity of the whole train; we should certainly not imagine that the driver of a brewer's dray or of a loaded goods van would inconvenience himself by moving off the track to allow an omnibus to pass, unless he were absolutely obliged by law to do so. Such, however, is found in practice to be the case, and no inconvenience results to the railway omnibuses from it.—*Burn on Horse Railways, p. 87.*

nary traffic of the country, and that, *in addition*, the railway would be available to carry fast traffic, either by lease to a company or otherwise.

Of course, such an argument is altogether a question of cost, and it is only under certain circumstances that it is applicable, but those circumstances are not so uncommon as might be supposed. Thus, the present cost of metalling of the Grand Trunk Road is, according to Mr. Login (*see* Professional Papers, Vol. III., page 354), 750 Rs. per inch per mile, or for the ordinary width, (16 feet,) and a depth of 9 inches, 6,750 Rs. The yearly cost of maintenance is 700 Rs. per mile for metalling only, which represents a capital of 14,000 Rs., or a total cost of 20,750 Rs. per mile.

In Malwa, according to Col. Cowper, (*see* Professional Papers, Vol. II., page 387,) the cost of what he calls 2nd Class Metalling (*i. e.*, with moorum) is 10,939 Rs. per mile; and the annual cost of maintenance is 2,935 Rs., equivalent to an additional sum of 58,700 Rs. per mile. This officer proposes a *Stone* Tramway on account of this very heavy cost; and an experimental mile was, I believe, laid down, on the Agra and Bombay Road, with what result I do not know.

The *Estimated* rate for Metalling on the 2nd Division, Lahore and Peshawur Road, in 1854, was 7,998 Rs. per mile, when prices were much lower than now; 16 miles were estimated at 10,895 Rs. per mile! What has been the *actual* cost I cannot say.

Now to determine the cost of an Iron Tram-rail road, we must first go into the details of its construction. (I will speak of the gauge hereafter). In America, the tram is spiked down to transverse sleepers. I would replace these in this country by a continuous foundation of masonry or

concrete, as shown in the diagram, bolting the rail right through at in-

tervals. The rigidity of such a substructure would be a disadvantage in a locomotive road worked at high speeds, but is not, I think, to be feared at ordinary speeds; some elasticity could be given, if thought desirable, by interposing a layer of felt between the iron and masonry.

Such a foundation, 18 inches wide and 2 feet deep, which should be enough in most cases, would require 31,680 cubic feet per mile; and this, at Rs. 14 per 100, a fair rate for this part of India, would amount to 4,435 Rs. Concrete would probably be more economical than masonry, and might often be advantageously substituted, but the upper layer should consist of stone or hard burnt brick on edge, as it would be subject to occasional wear from the wheels.

A width of metalling 7 feet wide and 6 inches thick would, at Rs. 10 per 100 cubic feet, cost Rs. 1,584. The wear and tear of this would be altogether far less than in the ordinary case, as it would be only that caused by the animals, and inferior metalling to that required for a common road would be absolutely better, as less injurious to the feet of draught cattle. Making, however, the same allowance of about 10 per cent., this would represent a further sum of Rs. 3,160.

We now come to the Iron work—the cost of which was as follows in England 10 years ago. Weight of rail, 35 lbs. per yard—pattern as in figure.

| | | | £ | s. | d | | £ | s. | d. | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rails,* | 55 tons, | @ | 7 | 10 | 0 | = | 412 | 0 | 0 | per mile. |
| Plates, | 267 lbs, | @ | 0 | 0 | 2 | = | 2 | 4 | 6 | |
| Spikes, | 320 lbs., | @ | 0 | 0 | 3 | = | 161 | 0 | 0 | |

these spikes are to be replaced by bolts, but I take this amount as probably sufficient.

Total £430-14-6.

It is difficult to form an exact estimate of the cost of freight from England, carriage up country, and expense of laying down; but I have consulted Mr. Campbell, the experienced Superintendent of the Roorkee

* The iron should be of the best quality of iron manufactured for railroad purposes, perfectly straight, and free from warp or twist, and of a uniform thickness throughout. The bars should be in lengths of twenty-four feet, and cut square at the ends, they should be punched with countersunk holes, in the centre of the rail, at intervals of three feet, and at about two inches from their ends.

The joints of all the rails should rest on a plate of boiler iron, quarter of an inch thick, imbedded in the masonry, and punched with two holes to correspond with the spike-holes at the end of the rails.

The rails should be bolted at every hole or at intervals of three feet; the bolt to pass right through the masonry in which it has been previously built and screwed up by a nut fitting in the countersink of the rail.—(*Adapted from Easton on Street Railways*, p. 66-7.

Workshops, and he considers that if the above price be doubled, it ought to be ample for everything as an *average* rate. Of course it would differ considerably in different parts of the country. This would amount to Rs. 8,615.

The life of such a rail, I think, may be safely taken at 20 years, so that 5 per cent., or Rs. 430 per annum, may be allowed for deterioration and repairs; this would, of course, add another Rs. 8,615 to the total cost.

The first cost of the Iron Tram-rail Road would therefore be:—

| | RS. |
|---|---|
| Foundation masonry, ... ... ... ... | 4,435 |
| Metalling, ... ... ... ... ... | 1,584 |
| Iron work, ... ... ... ... ... | 8,615 |
| Total Rs., ... | 14,634 |

ANNUAL MAINTENANCE.

| | |
|---|---|
| Metalling, ... ... ... ... ... | 158 |
| Iron work, ... ... ... ... ... | 430 |
| Total Rs., ... | 588 |

A pucka road, then, costing 10,000 Rs. a mile for metalling and 1,000 Rs. a mile for yearly maintenance, would be economically replaced by an iron tram-rail road—while the profit arising from the use of the rails for properly constructed vehicles would all be to the good. If the metalling were of inferior quality, of course the economy of the iron road would be still greater.

What the value of the railway itself would be it is almost impossible to estimate in general terms—it must obviously depend on the particular line of road to which it was applied—but as the difference between the cost of haulage over a metalled road and a railway (animal power being used in both cases) is about 8 : 1; it is clear that if the traffic on the road, other than what was carried by the ordinary carts, were transferred to the railway, a large saving would ensue.*

* It may be said that the tramway would be nearly as good as the railway, but the greater steadiness of a rail over a tram would give the former a very decided advantage, especially for fast traffic; and even for slow traffic, though the friction on the iron plate would be less than on a stone road, the continual friction of the wheel against the lip of the tram would be a drawback more than sufficient to counteract this.

Taking the case, however, where the price of met[illegible]alling is not so extravagant,—as in the figures given above for the G[illegible] T. Road, we shall have—

*First cost of Metalled road*, Rs. 6,750.

„ Iron tram road, Rs. 14,634, or Rs 7,884 more [illegible] than the road.

*Annual maintenance of Road*, Rs. 700.

„ Tram road, Rs. 588 or Rs. 112 less th[illegible]

which as representing a sum of Rs. 2,240, will reduce the diff[illegible] favor of the road to Rs. 5,644, and the question is whether the yearly interest on this sum, say Rs. 280, would be covered by the lease or value of the railway? Taking the difference in the cost of haulage on the road and railway at 8 : 1 as before, it would appear that if the traffic on the road other than what was carried by country carts were carried by the railway, a yearly mileage traffic of Rs. 320 on the road (or about 5,000 tons*) would cover the difference in cost; while everything beyond would be clear profit. That a more convenient road would as surely create traffic as an ordinary railway now does, there can be little doubt.

Probably it would be more economical to do away with the tram entirely, and to diminish the rail to a weight of 28 or 30 lbs. But this, of course, implies that the whole business of carrying is to devolve on the Government as the makers of the line, and this may be more than they are inclined to do.

Col. Yule's well known Report on a Horse Railway for Rohilcund (quoted in Vol. II. of my C. E. Treatise) and Sir W. Denison's paper on the same subject (*see* Professional Papers, Vol. II., page 250), contain data from which calculations may be made of the cost and profit for any particular line of road.

The *Gauge* for such a line as I have been describing should, I think, be 3 feet 9 inches, as shown in the diagram, if it is to suit the existing carts of the country. A common hackery measures 4 feet 5 inches in w dth from centre to centre of the wheel-tires, and these vary from 2 to 3½ inches in breadth. A gauge then of 3 feet 9 inches for trams 6 inches wide would give sufficient play to keep the wheels fairly on the tram without undue friction against the " lip."

A pair of bullocks, however, as usually yoked, require a width of 5 feet 6 inches to walk in, and would be better for more; they must therefore

* Or 20,000 3rd Class passengers per annum, say 60 per diem, at present railway fares.

walk outside the trams, one on each side and at a greater interval apart than they are usually accustomed to, though a third bullock could easily be added in the space between the trams. This would be the only change required in the ordinary hackeries, and I do not see how it could be avoided. The gauge of 3 feet 9 inches is only recommended on the above ground; of course, there would be a great advantage in having the animal traction *within* the rails, and if the rolling stock were made up on purpose, probably the Indian gauge of 5 feet 6 inches would be best for either bullocks or horses.

I have not estimated for any *Sidings*, because these are not absolutely required even for a single line. The lip of the tram would always permit hackeries to leave the track with little difficulty, and without injury, and this applies to any other unflanged vehicles that might use the tram. Even when the rail was used, by adopting the American pattern of wheel as described below,* sidings are not essential. As the traffic developed, however, they should doubtless be added for both kinds of traffic until the development was sufficient to require a double line.

On the French branch lines, they are designed of 1000 mètres (3,300 feet) long, at distances of 4000 mètres (2½ miles) apart. But our conditions are altogether different, and it would probably be sufficient to provide sidings of 500 feet at every mile, or better perhaps for Indian traffic, 250 feet at every half mile. This would only add one-tenth to the above estimate.

* In order to enable omnibuses to pass each other when travelling in opposite directions on the same line of rails, or to pass other vehicles travelling in the same direction, several ingenious contrivances have been invented for a movable or shifting flange, so as to enable the street railway omnibuses to travel on the road and on the rails with equal facility. Mr. Curtis' invention may be briefly described as follows :—The wheels of the street railway omnibuses are made rather broader than usual, and revolve loose upon the axle. A portion of the axle for about three inches in length, on the inner side of each wheel, is formed excentric for a depth of about one inch, or whatever depth may be required for the flange when in contact with the rail. Upon this excentric portion of the axle there is another wheel or disc abutting close against the bearing wheel, thus constituting a flange. This also revolves loose upon the excentric portion of the axle. When it is intended that the omnibus should run on the rails, the axle is turned half a revolution by a lever in communication with the driver; and the excentric portion of the axle is depressed, and the disc is lowered. This enters into the groove of the rail, and performs the same object as a fixed flange. When it is required that the omnibus shall run off the rails, the driver of the omnibus by a similar action with the lever turns the axle half a turn, and raises the excentric, and thus raises the disc out of the groove of the rail, and the omnibus can then be drawn off the rails.

Mr. James Samuel, C.E., proposes a contrivance which will answer the same purpose as a movable flange, in cases where the rail laid down is not a grooved rail, but similar to the New York tram rail. For this purpose he makes a fixed projecting flange to the wheel, the flange being of such a strength and width, that when the street railway omnibus is off the rails, it can run on the flange, and when on the rail, it runs on the periphery of the wheel. The same object may also be accomplished by other contrivances.—*Burn on Horse Railways, p.* 61.

I think it likely that in many parts of the country where granite or hard limestone was available, a *Stone* tramway might be employed instead of the iron, and possibly even stone might answer for the railway.

The weight and cost of a Cast Iron Tramway places it altogether out of the question.

Of course it has been impossible to do more than frame a *general* estimate, which must vary for every particular road, but I think I have made out a case for further consideration and experiment, which, if successful, would lead to important results. Should the Government think so too, I propose, on my approaching visit to Europe, and perhaps to America, to visit such Horse Railways as may be in existence, and report as to their applicability to this country; also as to the best form of rail. At present, there seems no information extant on the subject.

J. G. M.

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# Correspondence.

The Editor acknowledges, with thanks, the receipt of the following papers:—Steam Road Rollers in India—Telescopic Measurement in Surveying—American Roads—Fouracres' Stirrups for Block-sinking—Brake-power on Railway Inclines—On Oblique Arches—Repairs of G. T. Road—Reservoir at Boyd's Corner—Silt Process for Embankments—Report on Asphalte—Manufacture of Ransome's Stone at Bombay.

*To the Editor.*

*Ceylon Government Railway,*

*Director General's Department,*

MY DEAR SIR,—I enclose the design for our new copper tokens for the proposed decimal coinage. The obverse is the fac-simile of the Hong-kong dollar, the reverse is the talipot palm of Ceylon, with the value of the token in Singhalese character on one side of the palm, in Tamil (or Malabar) character on the other, as both languages are common here. The word "Sata" selected is not exactly Singhalese or Tamil, but derived from the Sanscrit, and has the advantage of being almost the same in both languages, and not very unlike "cent." I think we have carried the decimal movement, as the Governor is quite in favor of it, and we shall probably issue our new currencey in July, 1870. I hope India will take up the decimal movement strongly, as it would be an immense advantage.

Believe me, &c.,

COLOMBO,
*December 24th*, 1869.

GUILDFORD MOLESWORTH.

DEAR SIR,—Allow me to put you a question—

In Molesworth's last edition, he gives, "Levelling with Thermometer."

T = temperature of boiling point deducted from 212°.

H = height.

$H = 520\,T + T^2$

Thus, water boils, Kansam Pass, 185°.

212° less 85 = 127
520
14,040
729
14,769 height of pass above sea level.

Now, by this formula, it is absolutely requisite you should be provided with a vernier to the thermometer, as it is next to impossible to read nearer than half a degree, which makes 260 feet difference, which is an unsatisfactory result.

I do not know how the heights were calculated for the Trigonometrical Survey, but I have taken a great many during the last year, and with every care, but cannot make my results coincide with those, by a great deal, say 100 feet, which is not satisfactory.

Nor do I make the formula for heights taken by barometer any more correct, or at least any nearer agreeing. For instance, water boils here at 205°, the height therefore is 3689 feet (within 100.)° The barometer averages 27 inches. Temperature 90° Fahr. in the sun, probably 110° at the sea level; some days it is 110° in the sun, which would make the height different, which cannot be possible.

I should be glad to be enlightened where I am wrong, and put right.

Faithfully yours,
JOHN CALVERT.

KULU, KANGRA,
*January 17th*, 1870.

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[The G. T. Survey heights were determined trigonometrically. The "Boiling point" method is an approximation only.—ED.]

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*To the Editor.*

SIR,—Any suggestions on the subject of bridging the Hoogly cannot fail to i interest at the present moment. The largest bridges in the world, as regards t span, are I believe, as follows :—

*Stone.*—The Cabin John bridge, on the Washington Aqueduct, 220 feet spa 57 feet rise.

*Iron, Tabular.*—Britannia, 460 feet span ; Victoria, 330 feet span.

*Arched Girder.*—Hubenburg, 513 or 515 feet ; St. Louis bridge (projected), 500 feet.

*Straight Girder.*—I have no details of the largest. The spans of the Soane are only 162 feet (150 feet in the clear). [Those over the Jumna at Allahabad and Delhi are 202 feet.—ED.]

*Suspension bridges.*—East River, New York (projected). This bridge is to be pro-

ceeded with at once ; the measurements are taken from the plans in Mr. Roebling's office.

| | |
|---|---|
| River span, from centre to centre of tower, ... ... ... ... | 1600 feet |
| Length of each land span, ... ... ... ... ... ... | 940 „ |
| Distance between anchor wells,... ... ... ... ... ... | 3480 „ |
| Length of New York approach, ... ... ... ... ... | 1441 „ |
| „ „ Brooklyn, ... ... ... ... ... ... ... | 941 „ |
| Ascent New York side, ... ... ... ... ... ... | 3·44 per 100 |
| „ Brooklyn, ... ... ... ... ... ... | 1·87 „ „ |
| Elevation of grade in centre of span in summer above high tide, ... | 138 feet. |
| Elevation of bridge in the clear, ... ... ... .. ... | 130 „ |
| Elevation of floor in centre of tower, ... ... ... ... ... | 118 „ |
| „ „ at anchorage, ... ... ... ... ... | 85 64 „ |
| Height of tower above floor, ... ... ... ... ... ... | 150 „ |
| Total height above high tide, balustrade not included, ... ... | 268 „ |
| Elevation of New York terminus, ... ... ... ... ... | 36 „ |
| Elevation of Brooklyn terminus, ... ... ... ... ... | 68 „ |

The roadway will consist of a 15 foot side walk on each side, 15 foot central elevated pleasure walk and two 13 feet street car tracks on each side of the central walk

The cables are each to l ; 14¾-inch diameter and to be formed of 6036 No. 8 wires. The ultimate strength of one No. 8 wire is 3150 lbs., so that the ultimate strength of a cable is calculated at 9508 tons.

Each cable has to support 645 tons. The weight of 1560 feet of superstructure (river span) without cables is 3394 tons. The maximum transient load is 1164 tons.

Length of floor supported by short stays = 70 feet.

Length of floor supported by cables and long stays, = 1260 feet.

Aggregate maximum weight of 1260 feet of superstructure is 3681 tons ; deduct supporting power of longstays, 1101 tons ; leaving for the four cables 2580 tons, or 645 tons for each as above. The weight of the masonry in one tower is 65,000 tons, which, with the superstructure, gives a total weight on the foundation of 70,000 tons, or 4·37 tons per square foot of foundation. The rise and fall of cable, with a limit of 136° of temperature, is 3 feet 2 inches.

The Niagara railway bridge is only 800 feet between towers. The height of the owers above the floor is 80 feet, and height of rails above the river 245 feet. The r cables are each composed of 3640 No. 9 wires, and are each 10 inches in diar. The ultimate strength of the cables is 12,000 tons.

he Cincinnati Bridge for pedestrians and carts, including street cars, is 1050 feet ir span, the cables are composed of 5200 No. 9 wires, and are 12¼ inches in diameter.

Another suspension bridge has been constructed over the Niagara 1268 feet long, which the clear span is 1188. It is only intended for foot passengers and light vehicles.

As regards floating bridges, perhaps the best example now existing is that in which the railway is passed across the Rhine* at Maxan.

The length of the bridge is 1190 feet—

767½ the bridge proper.

211¼ each of the approaches.

* See No. CCLIX. of these Papers.

It consists of 12 bays resting on 34 pontoons of wood.

| | | |
|---|---|---|
| Two near the bank, each ... ... ... ... ... | 67·24 feet | 134·48 |
| Two bays capable of being opened, ... ... ... | 68·88 „ | 137·76 |
| Two „ each of ... ... ... ... ... ... | 41 00 „ | 82·00 |
| Two „ „ ... ... ... ... ... ... | 68 88 „ | 137·76 |
| Two middle bays, each ... ... ... ... ... | 68·88 „ | 275·52 |
| | | 767·52 |

The approaches at the maximum rise slope 3 3 in 100.

The breadth of the superstructure is 11 48 for the railway,
13 77 for a carriage way on each side,

Total, 39 feet.

The cost of the bridge proper = £16 3*s.* 2·4*d.* per foot run, and of the approaches £1 13*s.* 2·4*d.* per foot run.

ARRAH,
*February 20th*, 1870.

Yours truly,
J. M. HEYWOOD.

I met the Commission appointed by the United States Government to report on the suspension bridges in America, previous to sanction being accorded to the construction of the East River Bridge, and one of the members informed me he was perfectly satisfied of the feasibility of Mr. Roebling's project. That Engineer, since dead, had no hesitation in affirming that he should not be afraid of building a suspension bridge of 2000 feet span.

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*To the Editor.*

MY DEAR SIR,—In Irrigation Tract No. I, page 4, and table of evaporation for months of April to September,—take for instance month of April, 180 02 millimetres; is this the total number of millimetres for the whole month, averaging say 6 millimetres per diem ?

There seems to be a great discrepancy between the effective duty of one cubic foot per second as recorded here, and what is supposed to be the duty in India and even in Italy : 290 cubic metres per diem per hectare giving only 21 acres per cubic foot per second.

I have long been of opinion that we give far too high an average duty per cubic foot per second for water used in rice cultivation in India, excepting, of course, where a considerable rain fall steps in to help it ; and it appears to me a point of vital interest to be settled without doubt. If the duty in India approaches to any thing like that shown for Portugal, I believe the water rate ought to be raised proportionally in all places, at any rate, where a demand for more water exists for other khurreef crops.

The insalubrity universally ascribed to rice cultivation would make statistics of comparative mortality especially interesting and valuable.

My impression is that the insalubrity of lands, which are every year under rice crop, is accumulative ; and in such a case, it becomes a question whether a system of rotation should not be encouraged, or even enforced.

As a question of great social importance, both medical and irrigation officers have a special interest in throwing all the light possible on the subject, and I hope the time is not distant when we shall have a much larger amount of information in the matter.

Yours truly,
J. W. BARNES,
*Supdt. Irrigation Bhawulpore.*

BHAWULPORE,
*3rd February*, 1870.

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*To the Editor.*

SIR,—Will you allow me to describe to you, as well as I can, the improvement I have effected in the lighting of brick-clamps or kilns, (both names meaning the same thing,) as set and fired with coals at Acra.

The central-fire as applied to lighting clamps is as follows :—Our clamps are of three sizes, namely 70, 60, and 50 feet square at the base, respectively.

In the centre of these kilns an opening is left 3 feet in diameter.

The bottom of the kiln is put down with burnt bricks, leaving air flues in the usual way, with the exception of the wood flues. When the bottom of the kiln is laid down and the first course of bricks set in pockets, the first layer of coals is then put on.

*d, vertical section on line a b.*

In the centre, marked *a* in the plan, is placed a wooden core made of half inch board, 6 inches square and 4 feet high.

Round this core is put about a maund of split wood to the height of 2 feet The brick setting goes on in the usual way, only the bricks are kept a little more open just round the core, to allow of more coals at that spot.

Over the hole (which is very like a bee-hive standing on its base) the bricks are set over a little more in each course, until about the fifth course, the bricks butt against the core on all four sides.

As the kiln rises, the core is drawn up at the same rate, until it is considered necessary to light the kiln.

This is done by drawing the core completely out and putting in two or three full shovels of live coals into the hole, which fall to the bottom among the fine split wood placed in the bottom of the kiln at the commencement.

On these live coals, a little more split wood is dropped and allowed to burn for a short time until the fire has got well hold. Now a handful of straw is put into the hole, and pressed down with a bamboo just over the fire, and on the straw, two or three baskets of fine brick rubbish are put and rammed tightly down. This completes the operation.

The beauty of this simple idea is the success which attends its action.

The fire radiates from the centre in fine order—and at the same time, it drives off the steam much more effectively then when the kiln is lighted from the outside. The advantages are considerable.

First, It does not cost in labor, firewood and coals more than 1-10th of what it did by the old plan of lighting.

Secondly, The kilns can be lighted several days earlier, with less annoyance to the workmen while setting, than under the old plan.

Thirdly, The fire burns much more evenly, and rises up the kiln with greater regularity. The wood flues radiating from the centre, the whole body of the middle of the kiln is in good fire quickly.

I have tried this plan in seven or eight large clamps, and all in future will be so fired. I think the kilns will be burnt out in about three weeks less time, but of this I shall know more about a month hence.

I hope my explanation will be understood, and trust that you will use the information for the benefit of brick burners.

I am, &c.,
E. HICKMOTT.
*Superintendent, Acra Brick Factory.*
*Near Calcutta.*

*February 1st*, 1870.

# Correspondence.

The Editor acknowledges, with thanks, the receipt of the following papers:—Further Report on Fouracres' Well Excavator—Gunduck River Works—Construction and Repair of Ceylon Roads—Soane Canal Works—Notes on the Suez Canal.

*To the Editor*

My Dear Sir,—I observe in No. 27, Vol. VII., of the Professional Papers a letter from the Superintendent of Irrigation, Bhawulpore, referring to Irrigation Tract No. 1, and certain statistics entered therein. The points noticed by your correspondent are—

I. *Evaporation.*

II. *Duty of a cubic foot of water in rice irrigation.*

No. 1 is easily answered. The evaporation table given at page 4 of the tract represents the *monthly* evaporation. That shown for April, 180 02 millimètres, is the lowest, and that shown for July is the highest, 387 74 millimètres.

The former gives 0·236 inches evaporation per diem, and the latter 0·455 inches per diem. These results agree closely with the results gained by experiment in Madras, where large tanks exist. The evaporation in that part of the world is stated to be an average of 0 25 inches per diem in the cold, and 0·5 inches per diem in the hot weather, or taking the whole year round, a mean evaporation of one-third of an inch per diem.

II. *Duty for rice.*

To answer this is somewhat more difficult, but I have given some attention to the consideration of this point, and I think I can prove that the duty in Portugal as given by M. Andrade de Corvo is not very different to that which I have been in the habit of taking as a standard for India.

In the first place, I would remark that your correspondent has not apparently very closely studied the first six pages of the pamphlet. He has taken the table at the foot of the 4th page as his guide, and has, if I may be allowed to say so, somewhat misunderstood it.

Allowing that the following statistics are to be accepted as given by M de Corvo:—

Water absorbed by plants, 20 cubic mètres per hectare.

" " soil, 50 " "

he appears not to have noticed that the writer, M. Andrade de Corvo, has calculated

the large item of evaporation, not from a *mean* of the months during which rice cultivation is carried on, but from the *maximum* evaporation in any one month. This is an error in the original Mémoire. Again, your correspondent has added to the actual quantity used, the 100 cubic mètres which are used to keep up a flow through the basins (bassins nevelés), and thus naturally his calculation of the duty in rice of one cubic foot per second, or 21 acres, is considerably too low.

I hope I may be enabled to prove that the duty of a cubic foot in rice, even when based on M. De Corvo's liberal data, is considerably higher than 21 acres.

As will be seen, by reference to the Mémoire, there are two systems of rice cultivation in Portugal. One is the system of permanent inundation; the other that of periodical waterings The former is stated to be applicable to the kind of rice called *Oryza sativa communis*, and the latter is in use for the irrigation of rice called *O. mutica*.

In the first system, a gentle stream is kept constantly flowing through a series of basins, and as there is a constant daily supply larger than the amount absorbed and evaporated, it is to be presumed there must exist, in connection with this system of irrigation, a system of waste or drainage.

The second system is very similar to that adopted in India, so far as I know; and it is, therefore, more useful to compare the duty under this system with that laid down for India. Let us endeavour to work out the duty of one cubic foot of water per second on both systems, taking the figures and data given by M. de Corvo. I would remark, however, that his allowance of absorption appears excessive. 70 cubic mètres per diem for six months per hectare represents a depth of water over the area of nearly 0·28 inches daily for six months, and evaporation is in excess of this.

1. *Constant inundation.*

We have the following data.

(*a*.) The amount of water to be constantly present in the "bassins nevelés" is to be in depth 0·1 mètre (page 2, last line).

(*b*.) The daily absorption of the ground per hectare is 50 cubic mètres (page 4).

(*c*.) The daily absorbtion of the plants per diem per hectare is 20 cubic mètres (page 4).

(*d*.) The total evaporation from any surface from April to September is shown to be (page 4) 1722 millimètres = 1 722 mètres.

(*e*.) The daily evaporation is therefore $\frac{1\ 722}{180} = 0\ 00956$ mètres.

Hence, total daily expenditure of water per hectare (one hectare = 10,000 square mètres = 2·4712 acres) $= 50 + 20 + 95\ 6 + \frac{0\ 1 \times 10{,}000}{180} = 171{\cdot}15$ cubic mètres.

Now 1 cubic mètre = 35·32 cubic feet.

∴ 171 cubic mètres = 6040 cubic feet.

And 6040 cubic feet per hectare = 2444 cubic feet per second per acre.

This is, therefore, the daily expenditure per acre.

$\therefore \frac{2444}{24 \times 60 \times 60} = 0{\cdot}0283$ cubic foot per second expended in irrigation of one acre, and this gives a duty of a little over 35 acres per cubic foot per second.

2. *Periodical waterings.*—Now let us calculate the duty on this system.

From page 6 of the Mémoire, we get the following data for this :—

The water is supplied every 8 to 15 days, which is taken up in 2 to 4 days.

The process of cultivation only takes 5 months.

Let us assume that water is given once in 11 days, which is an average between 8 and 15, and that it is practically absorbed and evaporated in 3 days.

We must then calculate the daily absorption (50 + 20) previously given by calculating that $\frac{3}{11}$ of (50 + 70) takes place daily, and similarly for the daily evaporation.

We must also calculate that 0·1 × 10,000 cubic mètres are supplied once in 11 days, and, therefore, one-eleventh of this is the daily supply. Hence we have—

(*a*.) Daily amount of water thrown into basin

$$= \frac{0 \cdot 1 \times 10{,}000}{11} \text{ cubic mètres} = \frac{1{,}000}{11} = 99 \text{ cubic mètres.}$$

(*b*). Daily absorption of ground

$$= \frac{3}{11} \text{ of } 50 \text{ cubic mètres} = \frac{150}{11} = 13 \cdot 6.$$

(*c*). Daily plant absorption

$$= \frac{3}{11} \text{ of } 20 \text{ cubic metres} = \frac{60}{11} = 5 \cdot 6.$$

(*d*) Daily evaporation

$$= \frac{3}{11} \text{ of } 95 \cdot 6 = \frac{286 \cdot 8}{11} = 26 \cdot 1$$

∴ Daily supply required per diem per hectare

$= 99 + 13 \cdot 6 + 5 \cdot 6 + 26 \cdot 1 = 144 \cdot 3$ cubic mètres, say 145 cubic mètres.

Calculating as before, this gives a duty of 42 acres per cubic foot.

We have then—

1. Duty under permanent inundation system, ... ... 35 acres.
2. Duty under periodical watering, ... ... ... 42 „

The second system we have before said, is that generally used in India. From a reference to Baird Smith's book on Madras Irrigation, it will be seen that the Madras statistics of rice irrigation give 3 cubic yards per hour per acre, during the period of rice cultivation, as necessary for rice. This is equivalent to a duty of 44 acres per cubic foot per second.

No mention is made regarding rain-fall; and it is reasonable to suppose, from my experience, that this duty does not include rain-fall, *i. e.*, that 3 cubic yards, per hour, per acre, represents the amount of water rice requires, whether it derives such amount from natural or artificial sources. The correspondence between this duty in Madras and the duty found for Portugal, under a similar system of cultivation, is remarkable.

I am inclined to think that 45 acres per cubic foot per second is the statistical figure of duty of rice to be assumed when calculations (*omitting rain-fall*) are made regarding this crop.

$\frac{1}{45}$ of a cubic foot per second represents a rain-fall of a little more than 95 inches during the six months of rice cultivation, for

$$\text{Rain-fall in feet} = \frac{\frac{1}{45} \times 60 \times 60 \times 24 \times 180}{43560}$$
$$= 7 \cdot 93 \text{ feet} = 95 \cdot 16 \text{ inches.}$$

To find, therefore, the amount of water to be allotted to any rice district, we should, it appears, in estimating a project, base our calculations on rice requiring 95 inches of water.

Let $a''$ = total minimum rain-fall in months during which rice is cultivated, then the amount to be supplied by any canal irrigating a rice district should be

$$95'' - a''.$$

This may be styled the "working supply required," and on this the "working duty" may be calculated. The working duty of rice in acres per cubic foot, moreover, varies directly as the rain-fall, and inversely as the amount of water required from the canal.

Let $x$ = working duty.

$$\text{Then evidently } 95'' : 95'' - a'' = \frac{1}{45} \cdot \frac{1}{x} \therefore x = \frac{95 \times 45}{95 - a}$$

In the N. W. Provinces, the working duty (which alone concerns the Canal Officer) may be found from this formula for any district and for any year. It will be found to vary from 50 acres upwards, directly with the rain-fall in the months May to October.

Another point remains to be noticed in connection with the two systems of irrigation for rice in Portugal. The periodical system not only gives a higher duty, but as it only lasts for five months instead of six, the gross quantity of water expended is considerably less. This fact, though it will not affect the duty in *rice*, will naturally in a perennially irrigating canal, raise the *average* duty considerably.

There are two other points touched on by Mr. Barnes, these are—

*The rate for rice, and the insalubrity of its cultivation.*

There is little doubt, I think, that the present N. W. Provinces rates are, for rice, too low. The crop imbibes a very large quantity of water, and the return of grain from an acre is very large and profitable when sold in the market.

It might well be raised by half as much again as it now is. As far as my experience goes, rice is almost invariably followed in the N. W. Provinces by a grain crop; which is, not invariably, again followed by rice.

I have, however, already trespassed too far on your space, and hoping that you will insert this somewhat long reply in the next number, if only to provoke discussion on so important a point.

I am, dear Sir,
Yours sincerely,
W. G. ROSS, LIEUT., R.E.

ALLAHABAD,
*8th August*, 1870.

# Correspondence.

THE Editor acknowledges, with thanks., the receipt of the following Papers :—Restoration of the Mhow-Ke-Mullee Viaduct—Gunduck River Works—The Soane Anicut—Notes on Retaining Walls (4th Article)—Public Latrines in Ceylon—Breaks on Railways—Rainfall in Ahmedabad—Mahanuddy Sluice Shutters—Working of Fouracres' Excavator—The Fairlie Engine—Survey of the Irrawaddy Delta—Note on Artificial Cements—The Irrigation of French India.

## RAINFALL IN AHMEDABAD.

*Forwarded to the Editor.*

From Surgeon-Major, J. Pirie, M. D., Civil Surgeon, Ahmedabad.—To Colonel J. G. Fife, R.E., Chief Engineer for Irrigation, Poona.—Dated Ahmedabad, 16th July, 1869.

SIR,—Agreeably to the request conveyed in your letter of the 6th instant, I have the honor to report, for your information, the following particulars of the excessive rain-fall in Ahmedabad, in August last.

From the setting in of the monsoon, on the 8th June, to the 6th August 1868 eleven inches and 28 cents of rain had fallen, but from the night of the 9th, till noon of the 12th, wind and rain raged without intermission.

The greatest fall was on the 11th, when, within 24 hours, 18 inches and 12 cents were registered. The total fall in August was 34 inches and 68 cents, and the grand total rain-fall in Ahmedabad, up to 13th August, was 44 inches and 66 cents, more than double the quantity generally gauged during the season. On the 15th August the monsoon may be said to have closed, for after that date, only a few slight showers were recorded.

The river rose 19 feet at one of the gates situated at a short distance above the municipal water works. The flood was so sudden and rapid, that the river swelled like a raging sea, sweeping cattle, trees, and huts, all before it. Had the storm con-

tinued six hours longer, the city would have been inundated from the down-pour, and by the rush of water up the drains from the surging river. At several points the water rolled inside the gates in tidal waves, and the nullahs inside the city suddenly became torrents, uprooting and carrying away all within reach of their force.

On the Dhoolnakote side of the river, the high precipitous mud-banks against which the impetuous current dashed in all its fury, were sapped and hollowed out, as if done by an earthquake, and which are now evidence of the violence of the storm.

Throughout the city, houses, walls, and trees, were levelled on all sides, with the loss of a few lives, but much damage to property. It was also reported that on the 11th at 1-45 A. M., a slight shock of earthquake was felt, but this is not generally believed.

The season preceding the rains, was one of the hottest on record, and the monsoon appeared to gather over the central portions of Guzerat, and burst, accompanied with thunder and lightning, over the Collectorate of Ahmedabad; and will ever remain a remarkable event in Indian meteorological annals.

At the Shahibagh the river was fully 11 feet over the usual monsoon mark, and the garden. Its volume and velocity were sufficient to root up and carry away four or five trees.

It also swept away nearly half of the garden, excavating the ground to the depth of 16 feet, in a funnel form, but this was greatly to be attributed to the fact of there being a pucka-built tank, about 20 feet square, in the middle of the garden, and against this, the current seems to have dashed, and striking it at an angle of 65° it received a rotatory motion, and vortex like, hollowed out this large pit.

The iron piles of the Railway Bridge, in the course of construction at the Shahibagh, were bent and broken, and several were sunk, but I do not know the exact measurements of the flood at this point of the river.

As my observations are restricted to Civil limits, I am unable to give you any interesting particulars of the flood in Cantonments; but in the compounds the water was two feet deep.

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*From the same.—To the same.*

Dated Ahmedabad, 16th July, 1869.

SIR,—In acknowledging the receipt of your letter of the 22nd instant, requesting further information relative to the fall of rain, at different parts of the 24 hours, in the storm of last year, I have the honor to report the following additional particulars :—

Heavy rain began on the afternoon of the 10th of August, but the heaviest was from the forenoon of the 11th up to noon of 12th, from which time the storm gradually abated.

The rain was not continuous for 24 hours till the morning of the 11th, on which day, from 11 A. M. till 2 P. M., about 4 inches, and from 2 P. M. till 6 P. M., 4¼ inches were registered. Twice again, at nearly similar intervals, during the night, the rain bottle was nearly full, and when emptied for the fifth time at 6 A. M. on the 12th instant, about 2 inches were measured, making within the space of one day, a total fall of 18 inches and 12 cents.

## MAHANUDDY SLUICE SHUTTERS.

[*See No.* CCLXII. *of these Papers.*]

*Report on the condition of the Mahanuddy Centre Sluice Shutters after the experience of the Freshes of the year* 1869, *and showing the action that had taken place at various parts of the structure.*

*Morning of the* 28*th October*, 1869.

Present:—

| | |
|---|---|
| MR. J. P. H. WALKER, *Superintending Engineer, Orissa Irrigation Works, Cuttack.* | MR. J. MACMILLAN, *Executive Engineer,* |
| MR. T. S. ISAAC, *Superintending Engineer, Public Works Department.* | MR. LEDGER, *Assistant Engineer.* |
| MR. J. MACPHERSON. *Collector.* | MR. CAMPBELL, *Assistant Engineer.* |
| MR. R. ALEXANDER, *Civil Judge.* | MR. BEALE, *Assistant Engineer.* |
| | MR. G. H. FAULKNER, *Designer and Constructor.* |

*No.* 1 *Bay (South).*—Front shutters rose in two minutes except No. 1, and this did after some little delay and clearing of stones from the old dam and side pitching. All in good order.

*No.* 2 *Bay.*—Rose in two or three minutes. Back and front shutters in good order, except Nos 2 and 3, which require two or three screw-nuts.

*No.* 3 *Bay.*—One shutter went up at the commencement of the season. No. 1 Shutter, hook found to be broken, otherwise back and front shutters were in good order.

*No.* 4 *Bay.*—No. 1 Shutter, plank broken on top edge where the catch bracket is fitted on, and seems as if a large stone had fallen on it. It may have been caused by the hook and catch-roller being too good a fit, and the shutter swelling, as it was very dry timber. No. 2 Shutter went up at the commencement of the season, the hook being broken at the same place as No. 1 Shutter on No. 3 Bay. (*See* above.) Probably the swelling of the timber was here also the cause, as the casting shows a clean fracture. One chain of this shutter is broken. No. 3 Shutter has also one chain broken. No. 2 back shutter was twisted out of position and riding on its neighbour; the pin of one hinge being out, could not find if this was broken, or in the hurry of work last season had been left out. No. 3 back also deficient of pin; in all other respects the shutters were in excellent order.

*No.* 5 *Bay.*—No. 3 Shutter has one chain broken; all else in good order; rose well.

*No.* 6 *Bay.*—No. 1 Shutter has the plank of front shutter slightly broken near the hook bracket. The latter broken; swelling of the wood again the apparent cause. No. 2, plank broken at same place.

All the front shutters in good order, except the one that went up at the beginning of the season. Two back battens are broken. All rose well at command. Back shutters all in good order.

*No.* 7 *Bay.*—Front shutters all in good order; some difficulty was found in moving round the eccentric shaft, which appeared to be jammed. After the loss of, say, 1½ hours, it was moved by jerks, and all rose well. In No. 3 back shutter, a hinge pin was wanting; otherwise all was in good order and condition.

*No.* 8 *Bay.*—No. 2 Shutter did not rise this day; but on the next day, by the aid of a crow-bar, the catch was released and the shutter rose. The stream had been previously stopped by putting narrow planks down, abutting against Nos. 1 and 3 Shutters. The back shutters were then put up and all were in good order. Chain gearing to front shutters unsatisfactory. Catch and Eccentric to this bay also as above sketch.

*No.* 9 *Bay.*—Front and back all in good order; rose without the slightest hitch.

*No.* 10 *Bay.*—Chains of Nos. 4, 5, 6 and 7 all broken; so that the whole weight of water, 6 feet 6 inches, was borne by these shutters without other support than that afforded by the butt of the hinge and shutters on the lower beam.

These chains are only ⅝-inch railway-wagon chains. The others, excepting in one bay, are $\frac{11}{16}$ inch; no doubt ⅞-inch chain should be used.

Front shutters of the 10 bays went up, with the exception of one shutter, in 2½ hours.

Back shutters in good order. On the 31st October all were fixed in summer-season trim.

No trace on the upper side of the shutters was found of any crustaceæ, nor between the joints. A few were seen in the angles of the battens on the underside. All iron-work on the upper surfaces was polished, and in some cases was quite bright from the friction of the sand, &c., passed over with the current.

*The two last Bays.*—Some trouble was experienced in raising the back shutters, as the head of water between the shutters having increased about one foot, there was comparatively a great quantity of leakage water to work against.

The original plan of a valve in one of the back shutters of this bay should be carried out.

*Abstract of cost of Centre Shutters, Mahanuddy Division. Length of Sluices 500 feet.*

| Quantity. | Items. | Amount. | | | Total. | | |
|---|---|---|---|---|---|---|---|
| | | RS. | A. | P. | RS. | A. | P. |
| 762 cwts ... | Cast-iron .. .. .. | 7,932 | 11 | 3 | | | |
| 861⅞ „ ... | Wrought-iron .. .. . | 7,454 | 15 | 0 | | | |
| 4,927 c. ft. .. | Teakwood .. .. .. | 8,622 | 4 | 0 | | | |
| .... | Sundries .. .. .. | 2,094 | 0 | 10 | 26,103 | 15 | 11 |
| .... | Labor .. .. .. | 13,608 | 5 | 11 | | | |
| .... | Superintendence, at 20 per cent. .. | 2,721 | 11 | 0 | 16,330 | 0 | 11 |
| | Grand Total .. | .... | | | 42,434 | 0 | 0 |

Rate per running foot about Rs. 85.

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## FOURACRES' WELL EXCAVATORS.

[*See No.* CCLXXIV. *of these Papers.*]

From H. C. Levinge, Esq., C.E., Superintending Engineer, Soane Circle, to the Chief Engineer, Bengal, Irrigation Department,—Dated Arrah, the 1st July, 1870.

SIR,—I have the honor to forward herewith copy of a report by the Executive Engineer, Dehree Division, on the working of the Fouracres' Excavator and the economy that has resulted from its use in the bed of the Soane during a portion of the past season.

The Executive Engineer has gone very fully into the subject and collated the results obtained with the Jham on different works and at different times, comparing them with the working of the Excavator, showing the very superior advantage of the latter, both in time and economy.

But I beg to draw particular attention to the fact that during the past season the work was carried on under the greatest disadvantages. Labor was scarce, the men untrained and unaccustomed to the work, and the supervision was insufficient, more men and of a better class being required on the work establishment.

It commonly occurred that the sand taken out of the wells fell back into the "crater," which invariably formed outside, simply from want of a sufficient number of coolies to remove it fast enough, and of course, this retarded the progress of sinking, since the sand that fell back in this way had to be lifted out again from the inside.

During my last tour of inspection at the end of the month of May, I noticed at Baroon one set of men who had fairly got into the way of working the Excavator, lifting for a short time three Excavators full of sand every two minutes from a ten feet well; each was piled up over the cross head, and though I did not measure the contents, I am sure they were not less than two cubic feet: thus, three cubic feet of sand per minute were being lifted, and it was as much as could be done to remove it to the spoil bank as fast as it was delivered on the platform.

I have no doubt that next season even better results will be obtained, as some improvements have been made in the tool.

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From G. R LONG, ESQ., Executive Engineer, Dehree Division, to the Superintending Engineer, Soane Circle.—Dated Dehree, the 13th June, 1870.

SIR,—As directed in your memorandum of 5th April, I have now the honor to report for the information of the Chief Engineer as to the actual economy that has been found to result from the working of Fouracres' Excavator as compared with the usual method of Jham and diver.

Since I received your orders, I have been attempting to obtain from various quarters correct information as to the cost of the latter method. This seems to vary enormously; the different statements I have procured will be given below, but in many cases it is hard to know whether anything besides actual labor in sinking is included. It is clear, however, that the cost of excavation under like circumstances would have been, at the very least, four times as much by the Jham as it has been found by the Excavator, probably considerably more.

First, as to the work done by the Excavator and its cost.

There were sunk, in February, 40, and in March 71, blocks, most of which were 10½ feet long, 5 feet wide and 10 feet high; they were sunk in batches: the following table gives the sizes of each batch (including spaces between), the depth to which sunk, and the product of these, or cubical contents of sinking, without the external crater; on these cubical contents, the rates of work are calculated, and in all calculations of Jham work, the same plan is followed.

In February there were sunk—

| | Wells. | Total length | Breadth | Depth sunk | Contents |
|---|---|---|---|---|---|
| | | | | | c. ft. |
| 1st batch .. .. .. | 6 | 68 | 5 | 10¼ | 3,485 |
| 2nd " .. .. .. | 8 | 88 | 5 | 10¾ | 4,730 |
| 3rd " .. .. .. | 8 | 88 | 5 | 10¾ | 4,730 |
| 4th " .. .. .. | 8 | 88 | 5 | 10¾ | 4,730 |
| 5th " .. .. .. | 10 | 110 | 5 | 10½ | 5,775 |
| | 40 | | | | 23,450 |

In March—

| | Wells. | | Total length | Breadth | Depth sunk | Contents |
|---|---|---|---|---|---|---|
| | | | | | | c. ft. |
| 6th batch .. | 7 | .. | 78 | 6 | 10½ | 4,914 |
| 7th " .. | 3 (pier) | .. | 28 | 3¾ | 5¼ | 551 |
| 8th " .. | 3 " | .. | 28 | 3¾ | 5¼ | 551 |
| 9th " .. | 7 | 5 | 40 | 6 | 10½ | 2,520 |
| | | 2 | 22 | 6 | 10½ | 1,386 |
| 10th " .. | 3 (pier) | .. | 28 | 3¾ | 5¼ | 551 |
| 11th " .. | 8 | .. | 91 | 5 | 8½ | 3,867 |
| 12th " .. | 8 | .. | 91 | 5 | 8½ | 3,867 |
| 13th " .. | 8 | .. | 91 | 5 | 8¼ | 3,754 |
| 14th " .. | 8 | .. | 91 | 5 | 8¼ | 3,754 |
| 15th " .. | 8 | .. | 91 | 5 | 7¼ | 3,299 |
| 16th " .. | 8 | .. | 91 | 5 | 8¼ | 3,754 |
| | 71 | | | | | 32,768 |

The cost of excavating and sinking the 40 wells, including the windlass-men and men at the Excavator, the divers who were kept at hand in case of any thing going wrong, and the carpenters and coolies at hand to set right the gearing, but without anything for removing the sand when tipped over the side, or for shifting scaffold, or for incidental expenses which do not affect the economy of the Excavator, was, from the Day-books, Rupees 192-2-6, which is at the rate of Rupees 8-3-1 per 1,000 cubic feet of bulk of block sunk.

In like manner the cost of sinking the 32,768 cubic feet in March was Rupees 268-2-3, or Rupees 8-2-11 per 1,000; mean of the two, Rupees 8-3-0 per 1,000.

It may be thought that the second month should show an improvement on the first when the work was perfectly new to all concerned. The reasons that prevent this are four. *1st*, The smaller size of blocks, as in the three piers only 3¾ feet wide, from which much more sand in proportion to the bulk as given above had to be extracted, and in which, being only one foot clear width inside, very narrow Excavators had to be used, requiring as many men to work them, but bringing up only half loads; *2nd*, The low blocks gave less weight to force the blocks down; *3rd*

Some of the cross-wall blocks were of awkward shape ; *4th*, In the greater part of the wells, beds of pebbles were found, which jamming in the jaws of the Excavator, often caused half a load of sand to be washed out in lifting it. Allowing for these causes, I think the second month does show distinct saving on the first.

After this report had been drafted and all calculations made, I received the statement of April's work and expenses. It shows 82 blocks, containing 41,878 cubic feet sunk for Rupees 347-13-3, or at the rate of Rupees 8-4-10 per 1,000. I had not expected so favorable a result, for all these blocks, except 14, had passed through thicks beds of pebbles, many of them had been low and had less weight to sink themselves ; 18 had been blocks requiring the small Excavator referred to above ; the five largest had been sunk through alternate beds of sand and stiff clay, and having only bamboo curbs had taken five days. Some sets had to be sunk till the tops were $1\frac{1}{2}$ feet under water, which hindered the men, because they could could not see their work, Logs of wood were found under some blocks, two of which had to be dismantled in consequence, and the great heat in the bed of the river made the work visibly languid. Also I have received the first report from Baroon, where the blocks being of similar sizes, but brick-built (not plastered), are better fitted for comparison with the Solani and other works. 51 blocks in all, making 22,080 cubic feet, have cost, for sinking, Rupees 174-9-6, or Rs. 7-14-6 per 1,000. But the first 21 blocks were only four feet wide for piers and sunk till the tops were two feet below water ; the crater was therefore very large in proportion, and the latter part of the work hindered by the men not seeing what they were about. The Assistant Engineer also was discovering for himself how to use a tool new to himself and his workmen, without any one at hand to guide him. Leaving out of consideration these 21 wells, the remainder are 30 blocks sunk $10\frac{3}{4}$ deep containing 16,663 cubic feet, cost Rupees 120-5-6, or Rupees 7-3-6 per 1,000, being a rupee less than the average at Dehree and less than one-fifth the Solani (reduced) rate.

I have not in the above tried to stretch any point in favor of the Excavator. I have not left out of the account the first six blocks sunk in February, when even those who directed the work had to learn the proper use of the Excavator ; although these six blocks took *nine* days sinking, at the same expense per block per diem as all the rest which were sunk, some in two days, some in three, I have deducted nothing for the bad character of the masonry, although, as known to you, the lime proved so unexpectedly bad that the blocks had to be lined inside with plank and tied outside with bars and planks. The cost of these, of course, is excluded, but their presence was a continual hindrance, the Excavator hooking itself on the inner lining, while three times in the progress of each well, the work had to be stopped and the sand shoots removed, while one outside binder was taken off and the others raised higher, expenses, of course, running on. Nor have I deducted anything for the untrained men I have had to employ, though there is so much knack in properly working the Excavator, that if all men could always do, what has in several instances been done, viz., sink a block $10\frac{1}{2}' \times 5$ ten feet in two days by the labor of seven men and the occasional assistance of another, the above rate of Rupees 8-3 would be reduced to Rupees 4-4.

But under all these disadvantages, I have shown that the cost of excavating so much sand as will sink 1,000 cubic feet of block has been only Rupees 8-3. I have to request the comparison of this with the results of the Jham as detailed below.

If, however, it be asked what amount of sand has to be excavated to sink the 1,000

feet of block, I have to point out that this varies with the width of block, number sunk at one time and depth sunk. The crater of a narrow block will be as wide as that of a broad block for the same depth. I, however, made the experiment; all the sand excavated from a group of blocks, measuring 91 × 6 × 10 or 5,460 cubic feet of blocks (with interspaces) was carefully piled on a level place, and measuring the crater formed, and found correct. This is rather more than double the bulk of blocks, and as these blocks were wider than most we have sunk, I think it will be fair to assume the average (for blocks sunk 10 feet) at 1½ times the cube of masonry sunk. This is considerably less than the formula, given by Captain Goodwyn in the document I shall presently refer to, would assign to such a group of blocks. But, as he states, the greater the rate of sinking the less the crater that forms, and this is an advantage fairly due to the merit of the Excavator, which makes in a day at least four times the average progress of the Jham. Taking the excavation at 2½ times the block, the rate per 1,000 cubic feet of sand excavated and lifted 10 feet is Rupees 3-4-5.

I have now to collate eight different sources whence I have attempted to ascertain the cost of similar work at the same depth with the Jham. To a depth greater than 10 feet the Excavator has not been tried, but there can be no doubt that, with the modification of working designed by Mr. Fouracres, its advantage would increase considerably with the depth; for the cost of diver's work is known to increase in a rapid ratio, while the Excavator is independent of divers, and springs rather assist than hinder it.

(1). The first, the most detailed, and the most satisfactory source, because it is distinctly stated what are the expenses of labor for sinking only, and at the same time the most advantageous for the Jham, is Captain (Colonel) Goodwyn's elaborate paper on block sinking at the Solani Aqueduct, where there can be no doubt that all that good apparatus and skiful direction could do was done, while the extent of operations was so large as to eliminate all accidental circumstances.

Captain Goodwyn makes his calculations on what he calls "100 cubic feet of the modulus," which he explains (see his paragrahs 7-13) to be an inverted pyramid whose base is the base of the block and whose sides slope upwards at an angle of 45°. By this he shows that he makes an even rate for sinking at all depths. He then takes the work of five months at intervals of time, and finds the cost "per 100 feet of modulus" for *sinking only* on all the work done in that month; as the rate of wages and number of men employed varied during the progress of the work, he then reduces all to one standard, that of May 1848; next, as in some cases the sand was lifted over the side of higher blocks, he reduces all to what he calls the 12 feet standard. This was very nearly the lift in the Soane wells, and his rates per 100 cubic feet of modulus thus reduced are as follows:—

| | | Annas. |
|---|---|---|
| In May 1848 | (his paragraph 16) .. .. .. | 7·28 |
| " " 1849 | ( " " 17-21) .. .. .. | 9·70 |
| " " 1850 | ( " " 23) .. .. .. | 11·53 |
| " June " | ( " " 24) .. .. .. | 12·60 |
| " July " | ( " " 25) .. .. .. | 14·33 |
| | Total, .. .. | 5)55·44 |
| | Mean of all .. .. .. | 11·09 |

It is true that at the close (paragraph 29) Captain Goodwyn estimates the cost on a

large new work at 9 annas ; but this is an *estimate* only, the other, *fact ;* as he estimates for total expenses 20 annas, which he shows just above to have cost 23·5, probably he allows for experience and practice. But if so, it is not fair to compare this rate with that of the Excavator, whose first crude trials we are already comparing with the general out-turn of work by experienced hands.

This rate of 11 09 annas per 100 feet next needs to be corrected for increase in rate of wages. These are stated in his paragraph 19 to have been, in 1848, for Tindals at Rupees 6, and for Bildars Rupees 4 ; at the Soane, the rates paid are Rupees 7-8 and Rupees 4-6 : it will be fair, therefore, to add one-eighth to the above rate, making it 12·48 annas per 100 cubic feet of modulus.

Next, what would Captain Goodwyn's modulus be as applied to the groups of blocks sunk at the Soane ? It would vary with every size group ; but I will take from the list on page 2 of this report, the groups 88 × 5 × 10¾, as an average.

A crater having a base 88 × 5 = 440 superficial feet, and sides sloping upwards at 45° to 10¾ feet, would contain 16,023 cubic feet ; this is Captain Goodwyn's modulus for such a group. The net contents of the same set of blocks, on which the Excavator rate of Rupees 8-3-0 per 1,000 has been calculated, is 4730. Captain Goodwyn's rate "per 100 cubic feet of modulus" must, therefore, be increased in the inverse ratio to make a comparison, that is, $12 \cdot 48 \times \frac{16023}{4730} = 42 \cdot 277$ per hundred = 422·77 = Rs. 26-6-9 per 1,000 cubic feet of contents of block sunk.

But this is not the whole gain of the Excavator, for the large size of the Solani blocks gives them a further advantage in their less proportion of external crater. It appears that nearly all the blocks at the Solani aqueduct had a base of 22 × 20 = 440 superficial feet, or exactly the same as the group of Soane blocks taken above. But from their compact shape, the modulus of such a block by Captain Goodwyn's rule, to a depth of 10¾ feet, would be 11,272 cubic feet only, against 16,023 as found above for the Soane line of single blocks with 440 feet base. These are the proportions of sand to be excavated, and in making a comparison by rates of block sunk, it must not be allowed to tell to the disadvantage of the Excavator that it was first set to work on rows of narrow blocks with large proportional craters. The above rate of 422·77 annas per 1,000 must be increased in the proportion $\frac{16023}{11272}$, when it becomes 601·33, or Rupees 37-9-4 for the same work which the Excavator at first starting has done for Rupees 8-3.

Here already is a saving of seven-ninths of the cost of excavation ; yet it will be found, on examining the further authorities I have to quote, that they all make the Jham to be *more* expensive in proportion than thus shown.

(2). The second source of information is the Table of Rates in the North-Western Provinces about May 1864, published at Roorkee.

The work is described to be "sinking cylinder not exceeding 6 feet internal diameter and not deeper than 10 feet below spring level, exclusive of cost of masonry and of excavation of spring level."

The rates vary greatly in different Divisions from Rupees 2 to Rupees 11 per foot downwards. This must be from variation in the class of work. But I will assume all wells to be sunk to what is given as the maximum depth, and all to be of what is given as the maximum diameter, and further add 1′ 6″ to the diameter of each for masonry.

With these concessions, the bulk of block to 10 feet deep will be 441·78 cubic feet maximum taken as average.

| | | | | | |
|---|---|---|---|---|---|
| The cost of which at *lowest* rate in tables is | Rs. 20 0 0 | or | Rs. 45 4 4 | per 1,000 |
| ,, | medium ,, | ,, 76 14 0 | or | ,, 174 0 2 | ,, |
| ,, | highest ,, | ,, 110 0 0 | or | ,, 248 15 10 | ,, |

All over Captain Goodwyn's rate, the lowest five and a half, the highest thirty times the Excavator rate

If stiffer soils or other extras enter into the higher of these rates, take off half on that account, and the balance is still fifteen to one in favor of the Excavator. If stronger springs, these could not be stronger than in the bed of the Soane, where I have kept three months working in a 5-feet well without lowering the water 2 feet, and it is a special merit of the Excavator that it is independent of springs, and works better in 10 feet water than in the dry, for the bucket fills better to the cross head from the pressure.

(3). The third source of comparison is Captain (Sir P.) Cautley's Roorkee Manual of Well-sinking, page 57.

| | RS. AS. P. | RS. AS. P. |
|---|---|---|
| Here the cost of sinking 202½ running feet of cylinder (said to be mostly 6 feet outer diameter, in some cases 8 feet, so take 6½ feet as average) to 10 feet depth only, in sandy soil with springs is said to have been ... ... ... ... ... | | 450 0 0 |
| Deduct as from this table at assumed rates— | | |
| 60 Carpenters and smiths, at Rs. 0 4 0 ... | 15 0 0 | |
| 358 Laborers ,, 0 1 6 ... | 33 9 0 | |
| Sundries ... ... ... ... ... | 10 10 0 | 59 3 0 |
| Leaves for well-sinkers and windlassmen, that is, for labor of under-sinking alone ... ... ... ... | | 390 13 0 |

But 202½ feet of 6½ feet cylinder contains 6,719 cubic feet gross bulk. Then, as 6,719 : 390-13 : : 1,000 : 58-2 cost per thousand.

But this Manual is dated 1839, and since then wages have risen ; calculations from Captain Cautley's table will show that the pay of well-sinkers and windlassmen must have then averaged 2 annas, with a little more to the head-men. At the Soane it is 2 annas and 6 pie ; therefore, to make a true comparison, one-fourth must be added to the above, or Rupees 72-10-6 per 1,000 against Rupees 8-3 the Excavator.

(4). The fourth source is the cost of trial wells sunk by me in the Soane in 1868 to try the soil.

These wells were of brick, plastered externally 6½ outside, 5 feet inside, on knife-edged curbs, sunk with jham, windlass, and mot. They were sunk 6 feet at a time to 20 and 24 feet in depth. I have taken the cost only of the first 12 feet ; the rest was considerably more.

The cost on an average of two was for 12-feet sinking, or 398·16 cubic feet sunk, Rupees 21-7-9. Then, as 398-16 : 1,000 : : Rupees 21-7-9 : Rupees 53-15-6 per 1,000 cubic feet. But at this time labor had not risen at Dehree as it has since done ; coolies were paid 1 anna and 6 pie, and none over 2 annas a day ; as in case (3) it will, therefore, be right to add one-fourth to this, or Rupees 67-7-4 against Rupees 8-3 by Excavator.

(5). The fifth source is the past experience of Assistant Engineer Baboo Heera

Loll Mitter, who has sunk these blocks in the Soane in previous work with the jham on the Jubbulpore Railway, also with the sand pump.

I.—At the Rahary Bridge the wells were 13½ feet diameter. The Contractor was paid Rupees 10 a foot for the first 10 feet (after that 20) through pure sand, or Rupees 100 for that depth, which, containing 1,431 39 cubic feet, was at the rate of Rupees 69-13-11 per 1,000 , materials were found him, but he had to remove the sand, distance not stated, but, supposing 150 feet, which is unlikely, and allowing Rupees 2 per 1,000 on double the contents of the block, leaves a net rate only of Rupees 65-13-11 against Rupees 8-3.

II —At the Kutnee bridge, the average rate of sinking per foot downwards was Rupees 35 to Rupees 40, to 25 or 30 feet deep more than the above, but that of the first 10 feet cannot be stated separately.

III —At the Putroo Bridge, the sand pump was employed and daily labor. Here the wells were 10 feet diameter, and cost Rupees 11-8 to Rupees 12 per foot downwards for the first 10 feet. Take the mean Rupees 11-12, this is Rupees 119-8 for 785·4 cubic feet of well sunk, or Rupees 152-2-5 per 1,000. Deduct, as before, Rupees 4 for removing sand, leaves Rupees 148-2-5 per 1,000 against Rupees 8-3 by the Excavator.

The Contractors, Messrs. Waring and Hunt, were in this case paid the amount expended as above, plus 25 per cent.

(6). The sixth source is the expense at the Morhur Bridge, Grand Trunk Road. Being in the same district as the Soane, and a similar river; this is a fair case for comparison.

I have been informed by an Engineer who had seen the register kept and taken a note therefrom, that the cost of sinking (only) 2,465 cubic feet of well in the season, sunk only 8 feet through pure sand, was Rupees 555-1-7, or Rupees 225-2-6 per 1,000 cubic feet. This being several years since, it would be fair to add one-fourth for rise of wages, but this is superfluous.

(7). The seventh source is the rate now being paid by Mr. Kimber, Executive Engineer, for sinking wells by contract in Midnapore with jham and kodal.

Mr. Kimber pays for sinking wells 5 feet diameter, 6 feet deep, Rupees 2-8 each ; this for 117 8 cubic feet is at the rate of Rupees 21-3-6 per 1,000, but this is for 6 feet depth only, at which diving has hardly begun , also, at 6 feet deep, the sand can be lifted by hand over the side of the well. If the well were to be sunk 10 feet and all sand to be lifted that height, there can be do doubt but the rate would at least be doubled, or become Rupees 42-7 against 8-3 by Excavator, and this is contract work in a country where extensive operations have been going on for years, the other a commencement only with untrained hands and by daily labor ; and, as I have shown before, individual blocks have been sunk at the rate of Rupees 4-4 per 1,000.

(8). The last source is actual trial of similar blocks on the Soane, under circumstances precisely similar, or rather in favor of the jham.

I have sunk two blocks 10½ × 5 × 10 by jham and diver. The head diver was a man who for years has been retained on pay at Sherghotty as the best diver of the neighbourhood, and was recommended to me from thence. He has been with the Excavators since we began to work, and having seen their progress, protested with tears against being ordered to sink these blocks in the old way, declaring that I wished to take away his good name in his old age.

These blocks had the advantage over those sunk by the Excavators of being built of better masonry, and not encumbered with planks, &c., of being in a place where no pebbles were to be expected, and of being between blocks previously sunk, so that no end craters could form. The batches of blocks between which they stood had all been sunk in three days' working. The number of men required was one more for each well than for the Excavator, viz., one less (3) at the windlass and two more (5) at the jham to force it into the ground and to change in the diving. With the Excavator, as so much more stuff is lifted, it is four at the windlass and three in the well.

But the progress was very different. Instead of being sunk the whole 10 feet in three days, the two wells, worked with a double set, took 26 working days to sink, carefully looked after. The cost for sinking only as before was Rupees 69-14-10 for the two ; as their cubical contents with the foot interspace was 1,100 cubic feet, this is at the rate of Rupees 63-9 per 1,000, instead of Rs.8-3 by the Excavator, though, under like favorable circumstances as to absence of pebbles, &c., the Excavator has done the work under Rupees 6 per 1,000, the batches on each sides of this pair having cost, taken apart from others, Rupees 5-15 per 1,000.

I am now able to give an approximate reply to the enquiry as to the extent to which the Excavators have proved, and will prove, economical in working.

Taking the lowest of all the rates found for similar work by the jham, Captain Goodwyn's rate, the saving per 1,000 cubic feet of block sunk appears to be Rupees 37-9-0 — 29-6-0 = 8-3-0. But if the rate on Baroon blocks built of brick be taken, then Rupees 37-9-0 — 7-3-6 = 30-5-6 is the saving per 1,000.

There appears from the estimate to be, omitting all the Baroon shore-work, because it may find a clay foundation, 1,973,866 cubic feet of block to sink.

The saving on this amount would be Rupees 57,982. There is also a quantity of sand to excavate from below water level for sluice foundations and aprons. The Excavator will bring this up much faster and in larger loads than the jham or any other contrivance ; and, as the lower part of it will be 6 or 7 feet below water, it could not be done by ordinary coolies. I estimate the least possible saving on this at Rupees 2 per 1,000 ; the amount is, cubic feet 1,430,172 ; the saving therefore is Rupees 2,860.

Least saving in these two items, Rupees 60,842.

The probability is that the saving would be much more. If for the *least* rate I have formed, I estimate the mean of those from my sources of information (3), (4), (5) (8), all of which have a general agreement, I have a mean saving of Rupees 72-10-6 + 67-7-4 + 66-13-11 + 63-9-0 = (mean) 67-10-2 — 8-3-0 = Rupees 59-7-2 per 1,000, which on 1,97,366 cubic feet, gives the first item, Rupees 1,17,352 and total Rupees 1,20,212. Two of the above are from experiments in the Soane itself. The rate shown in my No. 6 from actual experience at the Morhur would show a saving which I do not like to calculate.

But the above is far from being the only saving. The element of time is to be taken into account. What time it will take to sink all the blocks depends on the supply of labor ; supposing that the rate of April only can be kept up and the same progress made on the other side of the river, it would take four seasons to sink all the blocks. But we have not yet half our number of excavators or scaffolds. Ordinary coolies, however, alone are wanted ; one diver to four blocks in progress, and one carpenter to eight, being sufficient. The supply of coolies is very deficient, but this

would tell still more against the jham. It appears that to sink 1,000 cubic feet of block by the Excavator are needed—

| | | | | | RS. | AS. | P. |
|---|---|---|---|---|---|---|---|
| $1\frac{3}{4}$ | Diver, 1 day, @ Annas 4-0 | ... | ... | ... | 0 | 7 | 0 |
| $\frac{7}{8}$ | Carpenter „ „ 6-0 | ... | ... | ... | 0 | 5 | 0 |
| $47\frac{1}{2}$ | Bildars, 1 day, „ „ 2-6 | ... | ... | ... | 7 | 6 | 9 |
| | | | | | 8 | 3 | 0 |

But from the last experiment by Jham and diver, to sink 1,000 feet appears to require—

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 75 | Divers, 1 day, @ Annas 4-0 | ... | ... | ... | 18 | 12 | 0 |
| 24 | Mates of coolies „ „ 3-0 | ... | ... | ... | 4 | 8 | 0 |
| 256 | Coolies „ „ 2-6 | ... | ... | ... | 40 | 0 | 0 |
| 1 | Carpenter „ „ 5-0 | ... | ... | ... | 0 | 5 | 0 |
| | | | | | 63 | 9 | 0 |

So that to sink the blocks by the Excavator in two seasons of 180 sinking days each (reckoning from the time the first masonry of the seasons may have set) would require to be kept at work only 10 divers, 5 carpenters, 260 strong coolies; so that it is clear it will not be labor for sinking that will prevent doing this. Delay this year has been from the depth of sand to be removed at the shore ends before masonry could begin; want of coolies for this, and for removing the sand taken out of the blocks, and want of Excavators and apparatus, and material in general, has hindered the work; whether masons, and material, and carriage, and general coolies for the contingent work can be found to do so much I am doubtful, but the sinking alone will not be the difficulty.

On the other hand, to do the work in that time by the jham would need to be kept at that work—

411 Divers.
131 Mates of coolies.
1,403 Strong coolies.
6 Carpenters.

In coolies alone 6 times and in divers 41 times the former; all others for building, removing sand, and for other works in in no way diminished. When these would be found I do not know, nor how many divers would need to be on pay to keep so many at work, for they are very subject to fever, and would also have to be imported from a distance at higher pay. But if from want of divers the whole work was delayed one or two years, the country would lose its benefits, and Government the interest on all outlay on the whole scheme of canals.

The benefit of Mr. Fouracres' useful invention will not, of course, be confined to this one work. Nor has this season shown all that it can do, for he has already devised and tried some improvements, nor will its full benefit be found till it is applied to deeper wells in which divers work to such disadvantage.

The delay in completing this report caused by the slow progress of the experiment by jham enables me to add that the last block of this season on the Dehree side was sunk on the 6th; 146 blocks having been sunk from 1st May to 6th June with about 16 excavators on the average at work, but these blocks being scattered, much time was lost in shifting the scaffolding.

## 'RECIPE FOR WHITEWASH.

*To the Editor.*

SIR,—I beg to enclose a capital recipe for making a Whitewash, which will withstand a heavy downpour of rain, and does not easily rub off on the clothes. I do not send it as original, but I have used it for many years with success.

UMRITSUR,
*24th September*, 1870.

Yours faithfully,
ALFRED PENNY.

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Take one maund of clean white lime, or shell lime—slake it thoroughly with hot water in a covered vessel.

Add, 5 seers of salt, dissolved in hot water;
3 seers of coarse rice, pounded and boiled to a thick paste (kanjee);
½ seer of glue, first cleaned by dissolving in hot water, the dirty refuse being rejected.

These ingredients are to be well mixed by stirring, and sufficient hot water is to be added to bring the mixture to the consistency of ordinary whitewash.

The brew should then simmer for a few hours over a fire, after which it should be strained and laid on *hot*.

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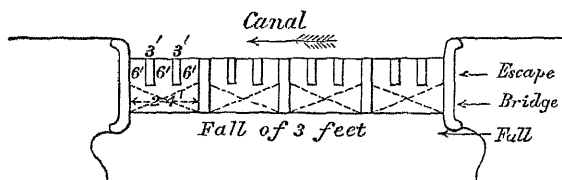
*To the Editor.*

SIR,—I want to calculate the velocity of discharge from an escape which I propose to build and so, as I am puzzled, I propose to you the problem. The plan is this—

The bridge is of four spans, and to each span there are 3 openings of the escape, and my difficulty is this:—There is a certain head, we will say $x$, in the canal from which we can calculate the velocity through the *Escape*, but as soon as the water has passed the escape the waterway (under the bridge) is suddenly enlarged, in this case by one-third, viz., from 18 feet to 24 feet; now what I want to know is, what will be the velocity of approach under these conditions with which the water will reach the fall, which is immediately below the bridge, and this it is which I do not see how to arrive at correctly.

---

*Reply.*

The water flows in the canal with a given head $x$. Hence the velocity with which it enters the escape is determinate. Afterwards the breadth suddenly expands from 72 to 96 feet. The effects of this sudden expansion are—

1*st.* Eddies.

2*nd.* Change of level of the surface of the water.

3*rd.* Change of velocity.

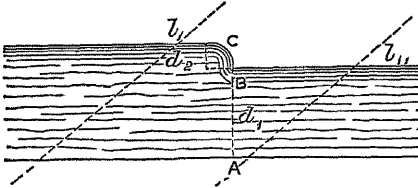
The eddies which are produced by the rush of water round the masonry consume

work and therefore destroy velocity. For the water in each after rotating for some short time about an axis fixed or moving gradually comes to rest as far as rotation is concerned, its velocity having been destroyed by friction with the neighbouring particles. This mutual action necessarily consumes work, and therefore tends to diminish the velocity. The effect of eddies cannot be calculated mathematically, unless the whole causes which produce the motion of rotation can be stated ; and as this is either very difficult or impossible, there appears to be no probability that the effect can be calculated.

Hence, either as in the case of friction, the effect or law of effect must be determined experimentally, or else a coefficient employed as in the case of the coefficient of discharge.

The 2nd and 3rd may be determined as follows :—

(It will be observed that the question is the converse to finding the headway caused by the erection of a bridge with several piers across a river).

Let D = discharge into escape.
$v_s$ = surface velocity, }
$v_m$ = mean velocity, } before expansion of breadth.
$h = d_{\prime} + d_{\prime\prime}$ = depth, }
$l_{\prime}$ = breadth of water.
$d_{\prime}$ = depth after }
$l_{\prime\prime}$ = breadth of water after } expansion.

Discharge at ABC is given by—

1*st*. For BC ...

$$\tfrac{2}{3}\, l_{\prime} d_{\prime\prime} \sqrt{2 g \left\{ d_{\prime\prime} + \frac{v_s^2}{2 g} \right\}} \ *$$

2*nd*. For AB ...

$$l_{\prime} d_{\prime} \sqrt{2 g \left( d_{\prime} + \frac{v_m^2}{2 g} \right)}$$

(To each of which the usual co-efficients may be added, as in the Madras Manual of Hydraulics, page 38).

Hence we have—

$$D = \frac{2}{3}\, c_2\, l_{\prime} d_{\prime\prime} \sqrt{2 g \left( d_{\prime\prime} + \frac{v_s^2}{2 g} \right)} + c_2\, l_{\prime} d_{\prime} \sqrt{2 g \left( d_{\prime} + \frac{v_m^2}{2 g} \right)}$$

also $d_{\prime} = h - d_{\prime\prime}$, where $h$ is the depth in the narrower portion of the stream.

This then is the equation to determine $d_{\prime\prime}$ or the change in the level of the surface.

Again since $v_m$ is the mean velocity in the wider part, we have—

$$D = l_{\prime} (d_{\prime} + d_{\prime\prime})\, v_m, \text{ or } l_{\prime}\, h\, v_m$$

And also $= l_{\prime\prime}\, d_{\prime}\, V_m$, if $V_m$ = mean velocity of water after expansion of breadth.

Whence, since

$$l_{\prime\prime}\, d_{\prime}\, V_m = l_{\prime}\, h\, v_m$$

the mean velocity $V_m$ of the stream in the wider portion is known, $d_{\prime}$ being obtained from

$$d_{\prime} = h - d_{\prime\prime}.$$

* Or more correctly, if $v_s$ is not small,

$$\frac{2}{3}\, l_{\prime} \sqrt{2 g} \left\{ \left(d_{\prime\prime} + \frac{v_s^2}{2 g}\right)^{\frac{3}{2}} - \left(\frac{v_s^2}{2 g}\right)^{\frac{3}{2}} \right\}$$

## No. Ia

# RIVER DAMS OR WEIRS IN FRANCE.

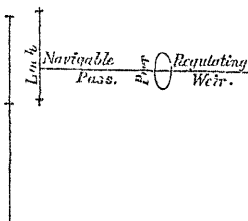
By Lieut. J. M. Heywood, R.E.

The river dams or weirs, which it is the object of the present paper to describe, are intended either to store up the water of the river for a certain time and then to allow its discharge entirely or in part, or merely to raise the level of the plane of its natural surface.

The object of discharging the backed up water, thereby flushing the river, is to produce a wave or artificial flood on which boats may float over the shallow places, and thus continue their course without obstacle.

This method of conducting the navigation is called intermittent, in contradistinction to the permanent, or continuous, which takes place when the water is kept permanently at a certain fixed level.

When an abundant supply of water finds its way into a river, as is the case during the season of floods, any storage or raising the level of the water becomes unnecessary, so that the dams are no longer useful for facilitating navigation, and even become excessively injurious in cases of extraordinary floods, owing to their impeding the flow off of the surplus water.

In order, therefore, to economise and raise the water during the lower stages of the river, as well as to pass off the injurious floods during the higher stages, whilst aiding in every way the requirements of navigation, the French have made their dams movable, and sometimes self-acting.

A movable dam generally consists of the following:—1st. A submersible lock on the towage side of the river.

2nd. A navigable pass, or opening, intended for the passage of boats when the water in the river is suffi-

ciently deep, generally placed at the tail, or down-stream, side of the lock.

3rd. A masonry pier between the navigable pass and regulating weir.

4th. A regulating weir or opening by which the flow of the river is regulated.

5th. A wing wall or abutment connecting the regulating weir with the bank.

6th. A house for the lock-keeper.

7th. Approaches on the up-stream and down-stream of both the lock and wing wall.

8th. An apron of large stones on the down-stream side of the dam along its whole length.

We propose here only to give a few general details of those parts which vary in the different systems, adding some particulars where the works are similar.

1st. *The Lock.*—The dimensions of a lock must depend on the method of traction employed—thus a convoy on the Upper Seine consists of 20 boats, extending along a distance of 1180 feet, and covering a breadth of 39 feet, so that the locks on that river are made sufficiently large to hold half a convoy at a time—their interior dimensions being $39' 4'' \times 590' 5''$. The head mitre cill should be placed as nearly as possible level with the plane of the bottom of the river; its depth is, however, variable, depending on the height of the dam. On the Upper Seine, the crest of the dam is generally raised 5 feet 3 inches, which allows of the mitre cill being sunk 2 feet 3·5 inches below the conventional low-water or summer level; the lock is submersible, being entirely covered during excessive floods. The head and tail walls are symmetrical, and founded on a layer of béton, about 5 feet thick; this latter is poured in between an enclosure of main and sheet piles. The length of each of the walls is 49 feet 2·4 inches. The length of the foundation is 59 feet, which leaves on the up-stream and down-stream sides two zones of béton, 5 feet in breadth, intended to receive the cofferdams.

A circular culvert about 11 square feet sectional area is provided in each side wall. The up-stream mouth opens into the lock chamber, where it is furnished with a valve; the down-stream exit leads to the river. These culverts assist in emptying and filling the lock chamber. The side wall, or rather dike, on the river side, is made of earth with a core of puddle in the interior—this latter measures 10 feet at the base and $3\frac{1}{4}$ feet at the crest—

the full breadth of the bank is 10 feet at the crown, increasing by slopes of 1 to 1. When rock is met with within a reasonable depth, a masonry wall may be conveniently substituted for the earthen bank. The slopes of the bank are pitched with stone, laid in hydraulic mortar or pointed. On the stones wooden rails are fixed to diminish the friction arising from the rough surfaces which would otherwise delay the movement of the boats. The gates, submersible like the rest of the lock, are of wood, worked by means of toothed wheels, set in motion by windlasses placed on the top of the side walls. The flooring on the down-stream side of the head and tail walls is of loose stone; this was originally covered with a 10-inch layer of Portland cement, but experience has proved this to have been an unnecessary addition.

2nd. *Navigable pass.*—The navigable pass is that part which is left free for navigation when the supply of water in the river is sufficient to give the necessary depth.

There are three stages or states of regimen in every river, during which the navigable pass must act in a different way.

(1). The Low stage, when all the water is to be economized. At such a time the navigable pass must be closed and the boats passed through the lock.

(2). The Medium stage, during which the navigable pass is left partially or entirely open, or left shut and opened when required for the passage of boats; the former method constitutes continuous, the latter, intermittent, navigation; in neither case is the lock brought into use.

(3). The Flood stage, when the river is full of water. At such a time, the more total the disappearance of every artificial obstacle to the flow, the greater the gain to the navigation, if such is possible at the time, and the greater in every case the safety to the different parts of the work; everything movable should therefore be laid flat on the bottom, or otherwise disposed of.

The length of a pass should be the least possible, in order not to increase the expense of construction and the difficulties attending the operation of opening and shutting it. It must, however, be of sufficient length to enable the navigation to be carried on with facility, particularly when the latter is conducted by flushes; the dam should be proportioned to the volume of water retained and the height to which it is held up; if the free space is too small, the wave passing through forms a cataract. As the opening is increased, this disappears and merely a rapid remains, on which the

boats can float without danger; the length must also be such that the open dam does not cause an afflux when the water is beginning to rise over the river bank. The site, supposing the circumstances the same, should be at a rise in the bed of the river, in order that the depth of the foundations may be the least possible; and it must also be remembered that the further the position is in the down-stream end of this shoal, the greater the length of the river commanded.

The flooring, viz., the crest of the fixed part of the navigable pass, may either be placed level with the low water stage of the river or with the bottom; in the former case, the object is to utilize the whole of the fixed portion of the dam, employing only medium sized machinery for the movable part, or if the machinery is of considerable height, to reduce the number of dams. This arrangement brings with it several inconveniences —thus sand, &c., settle on the up-stream side; navigation is prevented for a great portion of the year except through the lock, and a stop altogether is put to intermittent navigation; to obviate these, the latter method has been adopted in the most recent constructions.

The various systems which have been invented to meet all the requirements we have mentioned will be described in their order. In all, the navigable pass consists of a fixed base, placed nearly at right angles to the current, with a movable screen above, so arranged as to be capable of being rendered nearly water-tight at will, as well as of being opened or altogether removed. The two systems which have superseded all the others are those known as M. Poireé's and M. Chanoine's.

The former, invented in 1833, has been applied extensively on the Yonne, Lower Seine, &c.; the latter, invented in 1852, has been adopted on the Yonne, Upper Seine, &c.

3rd and 5th, *Pier and Wing-wall.*—The pier which separates the navigable pass from its regulating weir, as well as the wing-wall which connects the regulating weir with the bank, are similar in construction to the piers and abutments of bridges, and need not, therefore, be described here.

4th. *Regulating weir.*—The duty of the regulating weir is to afford a free passage for that water, which would, during the higher stages of the river, submerge the movable parts of the navigable pass; it has besides a double duty to perform, viz., to assist in the working of the navigable pass, and to economise the water during the low stages of the river.

To ensure the instantaneous opening of the movable screen at the critical moment, and its rapid closing when that has passed—one system, that of M. Chanoines', contemplates a self-action of the movable parts. The self-action of the panel frames is confined to those crowning the regulating weir, because the collection of floating bodies, &c., against the jointed arms is of no consequence where boats do not pass.

The difference between the movable and self-acting panels consists in the position of the axis of rotation; in these last it is so placed that the panel frames open when the overflow attains a certain height, whilst in the former it is fixed higher up, thereby assuring greater stability. The fixed platform or foundation on which the movable parts work, is more or less a permanent obstacle in the bed of a river, and its height must depend on a variety of circumstances; the higher it is raised as regards the low water level, the easier will be its construction and repair; the length depends on the height, and must be so settled as to ensure the free flow off of the water, both when the pass is closed and when the river is in flood; it should be as short as it is possible to make it without diminishing the regulating action. On the Upper Seine, they vary between 197 feet and 230 feet. On the Marne they are about 163 feet long, &c.

The direction is sometimes at right angles, and sometimes inclined to the axis of the river; when inclined the angle should not be less than 60 degrees, otherwise the gravel, &c., brought down by the water passing over the regulating weir are thrown into the navigable channel. An oblique weir allows of a discharge over its crest proportional to the length, if the velocity of approach of the water is nothing, but as the law no longer holds good after a certain velocity is attained, the increase in length produced by the obliquity of the weir produces no effect at the time of floods.

The systems now universally adopted are—M. Chanoine's, invented in 1852, and M. Desfontaines', invented in 1846.

8th. *The Apron.*—The arrangement of the down-stream apron must depend

(1). On the velocity of the water.

(2). On the duration of the discharge.

(3). On the depth of the stratum of water which covers the bottom of the river on the down-stream side.

(4). On the nature of the bed of the river.

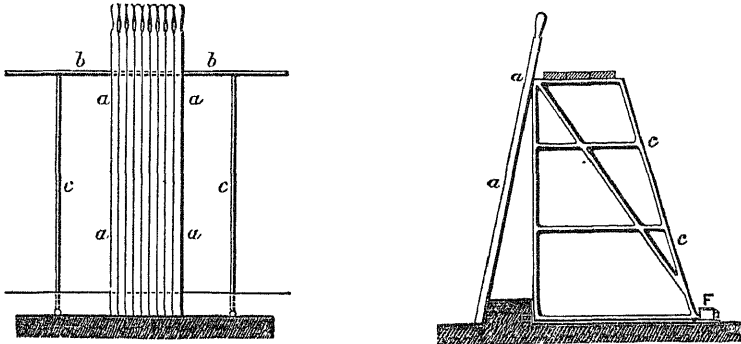
(5). On the volume of the water.

In the system of movable panels, when the navigation is constant, little or no scour takes place below the navigable pass, but when the navigation is intermittent, involving the opening of the pass once or twice a week, the force of scour becomes considerable, and the work, supposing the soil not to possess sufficient resistance, must be secured to a depth of at least 9 feet below the summer level. In the regulating weir, greater care is required, as the scour below is sometimes very considerable. In experiments tried on the Upper Seine, it was found that at one dam (Citanguette) a head of 9 feet of water carried away all the loose stone which had been thrown in to a distance of 49 feet, and the natural rock, which was 9·5 feet below the summer level was swept clean, notwithstanding the depth of water (10 feet) above it. At the dam of Evry, with a trial head of water of nearly 9 feet, the artificial flooring was removed to a depth of 13 feet. The original stones, which measured about a foot each way, being thus found insufficient, have been replaced by others of double the dimensions and of greater density. The first stones, though carried out of their intended position, yet serve a useful purpose in giving increased stability to the bed below them. In time, with care, the apron will, it is expected, have settled down into a solid mass, the gravel and sand brought down by the water tending to fill up all the empty spaces and bind the whole together.

At the dam of Joinville on the Marne, the last executed under the personal supervision of M. Desfontaines, and where he adopted a navigable pass closed on M. Poireé's system, only 39 feet 4·3 inches broad, greater scour was expected, as the whole river might accidentally be forced through the pass; in fact, a scour did speedily set in, extending for a depth of 13 feet to a distance of 100 feet beyond the foot of the down-stream slope; this has so far been prevented for the present by the introduction of a strong oak platform, nailed down to piles in the river bed, extending for a distance of 50 feet; this is however, considered merely a temporary expedient.

## M. Poiree's System.

In 1833, M. Poireé invented the system known by his name. It consists of a fixed dam, whose cill is below the level of low water; above this is placed a screen or superstructure of square prismatic bars of wood, known as "needles;" these rest at their feet against a projection or

plinth on the cill, and at their upper extremities against horizontal bars placed nearly level with the height at which it is intended the water shall stand; these horizontal bars are supported by vertical frames which also serve to carry a service foot bridge, so fixed as to be easily removed when necesssary. When the dam is to disappear, the needles, together

*a*, *a*, Needles. *b*, *b*, Horizontal bar. *c*, *c*, Vertical frames. F, Lower hinge.

with the service bridge and horizontal bars are removed, and the frames, turning on their lower edges, lie flat in recesses arranged for that purpose on the flooring.

Various modifications have been adopted since their first invention, thus the frames of the

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Dam of | Basseville, | erected in | 1834 | were | 4·92 | feet high placed | 3 28 | feet | apart. |
| ,, | Decise | ,, | 1836 | ,, | 5·90 | ,, | 3 28 | ,, | ,, |
| ,, | Epineau | ,, | 1837 | ,, | 6·986 | ,, | | | |
| ,, | Marne | ,, | 1841 | ,, | 6·691 | ,, | 3·28 | | ,, |
| ,, | Courbeton | ,, | 1849 | ,, | 8 036 | | | | |
| ,, | Bezons | ,, | | ,, | 10 824 | | | | |
| ,, | Martot | ,, | 1866 | ,, | 10 988 | | | | |
| ,, | Suresnes | ,, | 1867 | ,, | 10·824 | ,, | 3·608 | | ,, |

The needles of the Bezons dam are 13·12 feet long and 3·149 inches square, and weigh 19·84 lbs. when dry, or 29·38 lbs. when wet. Those of the dam of Suresnes are 13·12 feet long and 2·95 feet square. Such needles, when in position, are capable of supporting the pressure resulting from a head of water of 10 feet, but often break when moved during the variations which occur to the regimen of the river; thus in the dam of Suresnes, between the 2nd of June and 22nd of October, 1867, or less than 5 months, 500 out of the 900 needles in use or in store were broken;

of these, only 200 were destroyed by the shock of boats, the other 300 having failed, either in the operation of fixing or removing, or when exposed merely to the pressure of the water without any apparent reason.

The breadth of the service bridges has been increased from 1 97 feet to 2·95 feet, and even to 3·28 feet, as in the dam of Joinville (1867), thus enabling the sluice-keepers to work with greater security. To prevent the service bridge being submerged before the needles could be withdrawn, regulating weirs were added in some of the first constructed dams. Thus a regulating weir 403½ foot long, with a cill 2·7 inches below the standard level of the water, was provided in the dam of Epineau. One 1410 feet long, sunk 1·312 foot below the standard level, was given to the dam of Bezons. A fixed regulating weir allowablé for small depths of water is, however, very costly in cases where the depth is great, and may injuriously impede the flow of the water; for, if its crown is level with the standard or normal height to which the water is to be retained, it only acts when the works are already being submerged, viz., when the danger has arrived, and if below that level, it prevents that standard being reached by the water during the low stages of the river exactly at the time when most required; so that in some of the more recent dams, such as Menlan (6·56 feet) no regulating weir has been provided, whilst in the case of the Notre Dame de la Garenne dam (5·904 feet), one 32·8 feet long has been deemed sufficient.

To diminish this danger of submersion as well as to facilitate the navigation, it becomes necessary to withdraw the needles quickly; this is done by various plans at different places; generally the horizontal bars forming the upper supports to the needles are so arranged as to be easily removed by the sluice-keeper, the needles of each division are then carried down by the current, but being secured with ropes are easily recovered.

A still surer method of preventing the dangers mentioned consists in replacing the fixed regulating weirs by others crowned with a movable system, such as M. Chanoine's or M. Desfontaine's; this has been carried out on the Marne in the case of the last constructed dam (1867), viz., that of Joinville, where an opening 39·36 feet long, closed on M. Poireé's system, is joined to a regulating weir, 206·64 feet, made according to M. Desfontaine's plan.

*Method of working the dam when provided with no regulating weir.*— Supposing the dam to be completely closed, when the water retained is of

no great depth, the leakage between the needles will be small; but when the head increases and attains 10 feet, for instance, the volume of water lost, perhaps exceeds the summer discharge of the river itself. These filtrations may be reduced if the discharge is nearly that due to the summer level, by placing grass, &c., on the up-stream side; if the river rises, the sluice-keeper removes, in that part of the dam furthest from the lock, a certain number of needles in each bay, sufficient to enable the increased discharge to flow off, the others being left to divide the current. If the river falls again, the guard replaces the needles he took out. When the rainy season arrives, the sluice-keeper or guard passes ropes in each set of needles as they stand, and attaches them to the bank; directly the head of water has been reduced to a height previously settled by the withdrawal of the needles, the frames are lowered into their places, care being taken that they lie flat on the bottom and in no way project over the flooring. When the opening is completed, the guard recovers the needles, which float a short way on the down-stream side of the dam; when the time of the flood has passed, the needles are arranged ready for use; the whole or part of the frames are raised; some of the needles are placed in position; others are added in order that the water may be kept at the standard level.

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M. Chanoine's System, *(applied on the Upper Seine).*

The system bearing M. Chanoine's name was invented by that Engineer in 1852. It has since been applied on the Upper Seine, Yonne, and Marne. We propose to consider the details of those dams which have been completed on the former river, and this we do both on account of the full and clear descriptions given by the inventor and other Engineers, and because all the latest improvements have been adopted in the construction of these dams as experience demanded. Each dam consists [*Plates* I., II., III.]

A. The lock. B. Navigable pass
C. Regulating weir. D. Sluice-keeper's house.

1st. Of a submersible lock placed along the towing-path side of the river.

2nd. Of a navigable pass, furnished with the movable panels which constitute a portion of the invention to be described; this pass is generally attached to the tail of the lock.

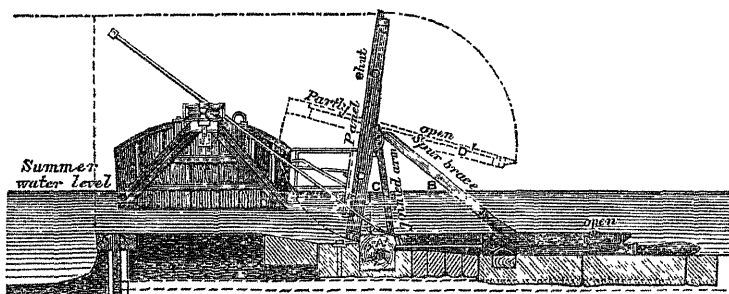
3rd. Of a pier of masonry placed between the navigable pass and regulating weir.

4th. Of a regulating weir filled with self-acting movable panels, these constitute another portion of the Chanoine invention.

5th. Of a wingwall joining the regulating weir with the river bank.

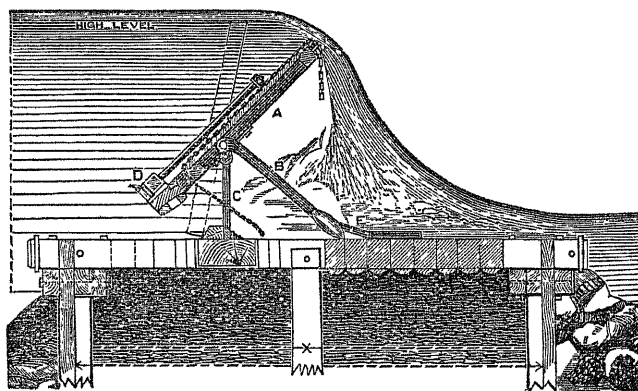
6th. Of a house for the sluice-keeper.

7th. Of an apron on the down-stream side of blocks of rough stone.

Briefly—a panel consists of a framework of wood or iron turning round on a horizontal axis, fixed to the head of a jointed arm, which itself revolves on its lower extremity; this latter being firmly let into the flooring. A spur brace keeps the panel frame raised, but can be lowered by a sliding bar lying flat on the cill. The cill of the navigable pass is sunk 1 foot 11·5

inches below the standard low water level, and varies in length between 132 feet 6 inches and 179 feet 6 inches. It is surmounted by from 31 to 42 panels, each about 10 feet high and 3 feet 11 inches broad; a space is left between each of 2 inches when the panels are raised and the panel frames upright—the fixed height of water to be retained above the lowest level is 7 feet 10·5 inches; when the panels lying down flat on the flooring are to be raised, a boat furnished with a windlass is moored to the wingwall, or to one of the panels already raised, and the power brought to bear, as we shall describe hereafter. In an hour, a pass of 164 feet can be easily closed.

To lower the panels and open the pass, two windlasses fixed on the wingwalls are used; these windlasses act upon the sliding bars, which, drawing the spur braces at their lower ends, remove them from the check

plates against which they abut; the panels thus losing their supports drop down on the flooring. A pass 164 wide can be opened in 4 minutes.

The regulating weir, varying in length from 198 feet to 230 feet, is composed of a fixed part raised 1 foot 7·6 inches above the low water level, with movable superstructure of self-acting panels; the panels are from 43 to 50 in number, each has a height of 6 feet 4·75 inches, and a breadth of 4 feet 3 inches; the distance left between every two adjacent panels is 4 inches. When the movable portion is upright, the crest is level with that of the panels in the navigable pass, viz., 7 feet 10·5 inches above the low water level. The axis of suspension of each panel frame is fixed at about one-third of its height on the head of the jointed arm, so that a layer of water, 4 to 6 feet deep, overflowing the crest, may initiate the movement of the panel frame on this axis of rotation. The

degree to which the panel frame is to be opened is limited by a chain, as the sensibility of the frame to return spontaneously when the water level falls, depends on this angle. [*Plate* II., *Figs.* 4, 7 *and* 8.]

When the self-acting panel frame slopes from the up-stream towards the down-stream side at its final angle of 15 degrees below the horizontal, it only recovers its upright position as soon as the water has fallen 3 feet 3 inches below the normal navigation level; if, on the other hand, the slope is from the down-stream to the upper side, the panel frame rights itself directly the overflow on the crest ceases, but the sensibility diminishes rapidly as the opened panel frame approaches the horizontal position.

If the panel frame when opened should be inclined at an angle of 45 degrees above the horizontal, it returns of its own accord to the upright position immediately the water falls 6 inches below its normal or standard level.

If the panels of the regulating weir are laid flat on the flooring, and it is required to raise them, a boat is employed in the same manner as we have described for the similar case of the navigable pass. These explanations will suffice to show the method of working a dam of this description.

Supposing the dam to be closed and the discharge of the river to be nearly that which occurs when the water stands at the lowest level, the leakage between the panels tends to lower the pent back water below the normal level; the spaces are therefore stopped up by "needles," or simple planks applied on the up-stream side. If the river rises, these are removed; and should its discharge continue to increase, the standard level being overpassed, the water will fall over the crests both of the navigable pass and regulating weir. When the depth of the overflow exceeds 4 or 5 inches, one or two of the panel frames of the regulating weir will open of their own accord, others will follow, until the number is sufficient to carry off the excess discharge. When this is effected, and the 4-inch overflow remains at that height, those panel frames not yet open remain upright. If the discharge of the river diminishes, the overflow also decreases, until it falls to the standard level; the panel frames still continue open; on a further fall, however, of 3 or 4 inches, some of the panel frames spontaneously right themselves, and before it is lowered 6 inches, the whole are upright. If a sudden and high flood descends the river, the regulating weir opens of its own accord, and so gives relief until the navigable pass is cleared, which can be effected in a few minutes by means of the sliding bars. When the season arrives in which there is sufficient water in the river, the panels both of the regulating weir and navigable pass are laid flat on the crests of the fixed parts, and the river becomes free. When the river falls, the movable machinery of the regulating weir is raised from the flooring, but the panel frames remain open on their axles, and continue so till the navigable pass is closed. As the fixed portion of the regulating weir only rises 1 foot 7·5 inches above the summer level, the head of water caused by it does not materially affect that operation. We now proceed to enter more into details.

*Description of a panel of a navigable pass.*—A panel consists—1st. Of a frame of wood capable of moving on a horizontal axis, placed in a direction at right angles to the current. When this frame is upright, it is supported by this axis, and rests at its lower extremity against a cill fixed in the flooring of the dam. [*Plate* I., *Figs.* 1, 2 *and* 3.]

2nd. Of an iron-jointed arm carrying the horizontal axis just mentioned; the two extremities of the base of this jointed arm fit into sockets fixed on the cill, against which the lower end of the panel frame, when upright, abuts in such a manner that the jointed arm can turn on its base, bringing with it the panel frame.

3rd. Of an iron spur brace having its upper end connected with that of the jointed arm, while its lower end abuts against an iron check plate fixed down to the flooring.

These are the component parts of the panel. The jointed arm and spur brace, when in their place, form a triangle, having at the apex the axis on which the frame rotates; the frame supported on this axis and resting at its lower end against the cill of the flooring bars the flow of the water in the river.

A navigable pass is made up of a number of such panels. The spaces between each panel, at first, varied between 18 inches and 6 inches, but have since been greatly diminished; the other parts of the machinery in a navigable pass are merely added to raise or lower the panels.

*Machinery for lowering the panels.*—Supposing the panel to be closed. If the foot of the spur brace, which, under such circumstances, rests against the check plate on the cill is drawn on one side of that check plate, it is clear that the spur brace, losing its support, will slide forward along the breadth of the flooring in the direction of that pressure which acts on the panel; also that the jointed arm turning on its base will follow, so that the two will be flat, in the same line, on the flooring, covered above by the wooden frame which must accompany them.

The spur braces are acted on by means of an iron bar placed horizontally on the flooring; this bar is provided with projecting tongues which draw the spur braces aside when the panels are to be lowered. [*Plate* II., *Figs.* 1 *and* 2.]

The bar is toothed at its extremities and is set in motion by spur gear; by this means the necessary movement is easily given to the bar, and by it to each of the spur braces. [*Plate* III., *Figs.* 6, 11 *and* 13.]

The bar, after the panels are lowered, must return to its former position, and be in readiness before the panels are again raised; consequently, the spur braces and jointed arms must, when down on the flooring, lie in such a way as not to interfere with its free movement.

*Machinery for raising the panels.*—The panel frame is divided by its axis of rotation into two parts—the upper and lower segment or leaf. If the foot of the lower segment or leaf is fixed on the cill of the dam, and an attempt is made to pull up the upper segment by attaching a hook to its head, it will be found that the resistence experienced increases with the head of water, and becomes so great when that head reaches a foot as to render the operation nearly impossible. In practice, the method of working is reversed; the lower segment is fitted with an iron handle; this the sluice-keeper stationed in a boat seizes by means of an iron hook; as he pulls, the lower segment rises above the flooring and drags up the jointed arm and spur brace. When the whole piece of machinery has arrived at the end of its course, the foot of the spur brace rests against the check plate, and the supporting frame made up of the spur brace and jointed arm is constituted; the panel frame is suspended on its axis of rotation and the lower segment is held by the iron hook. If the lower segment is heavier than the upper, a slight push, after detaching the hook, causes the panel frame to assume the upright position. The arrangements by which all these pieces perform their intended functions with precision and regularity require explanation.

*Axis of rotation of a panel frame.*—The forces which act on a panel frame standing upright on its jointed arm, and immersed in water, either tend to open it by causing it to revolve round its axis, or on the other hand to keep it in its upright position. [*Plate* I., *Fig.* 1.]

The former are—

The pressure of the up-stream water on the upper segment.

The pressure of the down-stream water on the lower segment.

The weight of a part of the upper segment.

The live force resulting from the velocity of the up-stream water.

The forces which act in a contrary direction are—

The pressure of the up-stream water on the lower segment.

The pressure of the down-stream water on the upper segment.

The weight of the lower segment.

A part of the weight of the upper segment.

PLATE I.

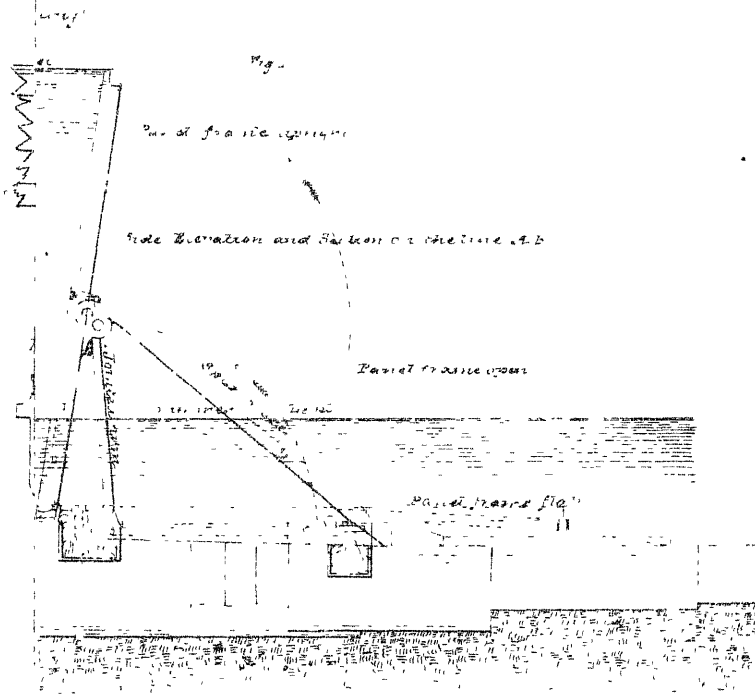
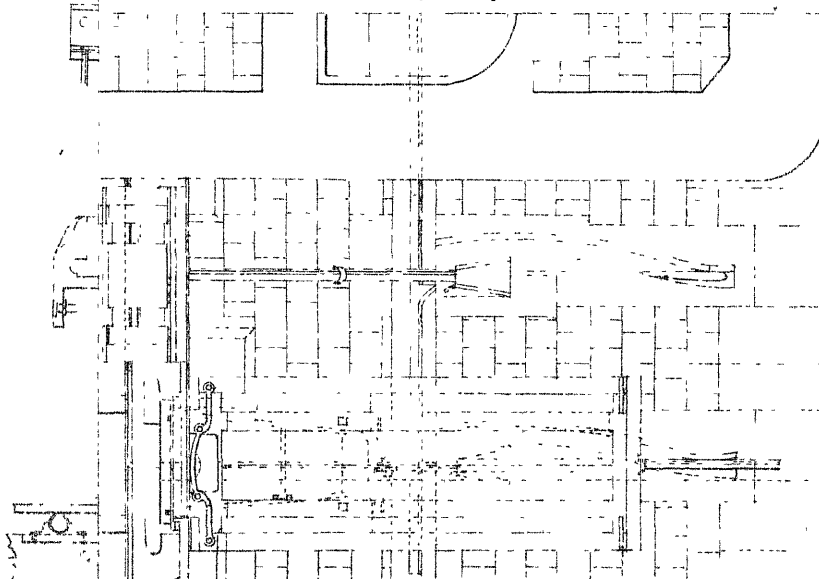
Fig.

Panel frame upright

Side Elevation and Section on the line A B

Panel frame open

Panel frame flat

Plan of a part of the flooring of the Navigable Pass Fig 2.

The friction caused by these forces on the axis of rotation.

The relation of equilibrium between these forces is complicated; it is sufficient to note here the following laws deduced from experience :—

1st. If the length of the lower segment is half that of the upper, there will be equilibrium between the different pressures exercised by the up-stream water when it is level with the summit.

2nd. If the upper segment equals the lower, there will never be any equilibrium, no matter what the depth of the sheet of overflowing water may be, the pressures on the lower segment will always exceed those on the upper.

Hence, the conclusion is arrived at, that the axis of rotation should be placed between one-third and one-half in the case of those panels which are not self-acting, and nearly at one-third for those intended to open spontaneously.

Further, it has been found—

1st. That the pressure of the down-stream water assists the revolving open of the panel frames on their axis, but that this tendency is completely destroyed by raising the axis a few inches.

2nd. That the lower segment can be so weighted as to counteract the action of that part of the upper segment not immersed in the water.

3rd. That the friction of the axis of rotation in its sockets is immaterial, the resistance being overcome by an addition of an inch or two in the depth of the sheet of overflowing water.

4th. That the effect of the live force due to the velocity of the up-stream water is very slight when the flow of the unimpeded river is naturally low, and when the overflow does not exceed 4 inches; but increases rapidly when the water in the river is so high as to submerge the axis of rotation of the panel, and when the overflow attains or passes 6 inches; generally, this force increases with the velocity of the up-stream water.

The panels of a navigable pass should not be self-acting, as floating bodies accumulating against the jointed arms may, by remaining between them and the spur braces when the panels are lowered on the flooring, keep the machinery raised above the cill, and thus render the passage dangerous for boats.

In consequence of these various considerations, the axis of rotation of a panel is so fixed that the height of the upper segment may be 7-12ths of the whole, and that of the lower segment 5-12ths. The total length

of the latter is, therefore, composed of this and the part resting against the cill.

For panels rising vertically 9 feet 10 inches above the cill, this dimension is 3·15 inches; the play between the foot of the panel frame and the following is 78 inches.

Consequently, the total length of the lower segment, = 4 ft. 5·53 in.
and that of the upper segment, = 5 ,, 8·9 ,,

10 ,, 2·4 ,,

*Jointed arm.*—The axis of rotation of a panel frame forms the head of the iron jointed arm previously mentioned; the two extremities of this head are pivotted into iron collars fastened to the woodwork of the panel. [*Plate* II., *Figs.* 1 *and* 6.]

The total height of the jointed arm is equal to 5-12ths of the height of the panel frame above its cill, and the depth of the recess in which the panel lies when laid on the flooring. This depth being 8·66 inches below the cill, the height of the jointed arm up to the axis of rotation, viz., the axis of the pivots of the head, is 4 feet 10 inches. If to this is added the radius of the pivots, and the play at the junction of the jointed arm with the spur brace, the height is increased to 5 feet 3·37 inches.

Theoretically, the jointed arm should be vertical when the panel is upright, as every deviation from that position uselessly increases the length of the component parts as well as the pressures they are exposed to; but in practice a slight inclination has been given, as thus the different pieces can be better fitted on with the others.

The jointed arm has a trapezoidal form, being 2 feet 6 inches at the foot, and 1 foot 5·7 inches at the head; these breadths are fixed so as to suit the dimensions given to the wooden frame of the panel and the sockets on the cill. The foot of the jointed arm is terminated by pivots, which turn in grooved iron sockets, bolted and screwed to the wooden cill of the dam. [*Plate* II., *Figs.* 6.]

To fix the jointed arm, the pivots of the foot having been placed in the grooves of the sockets are pushed into the position they are intended to work in, close to the grooves, the latter are then closed by pieces of wood: these pieces of wood are covered with iron at those points where they meet the pressure of the uprights of the jointed arm when the panel frame is raised; for in this position the uprights rest against the wood,

so that the latter limits the motion of the jointed arm. If it should be necessary to take the jointed arm to pieces, the block of wood is first removed by means of iron pincers, then the foot pivots are brought into the grooves: the operation is easily performed even under water.

*Collars of the pivots on the head of the jointed arm.*—These collars are fastened to the intermediate uprights of the wooden frame of the panel. They are symmetrical, and are fixed down to the frame by two bolts and a screw; each is provided with a check piece, against which the corresponding upright of the jointed arm rests when in the vertical position, as well as the panel frame when fully open, viz., when inclined from the up-stream to the down-stream side at an angle of 15 degrees below the horizontal. [*Plate* II., *Fig.* 6.]

These checks have been found necessary under the following condition:—When the panel is lifted, the lower segment of the frame has a tendency to rise, and the upper to fall, till it meets a point of support on the spur brace. This is no great inconvenience when the head of water in the navigable pass is inconsiderable, but as the number of panels raised increase, the breadth of the pass to be closed diminishes, and the head of water, consequently, becomes considerable; it then presses upwards under the lower leaf with great force, and prevents its being pushed down. To remedy this, it is only necessary to limit the inclination of the panel frame. At the dam of Conplans, two small chains, attached to the cross bar of the jointed arm and the lower leaf of the panel frame, are substituted for the checks.

*Woodwork of the panel.*—The woodwork consists of four uprights, of a top and bottom cross piece, of an intermediate cross piece, and of planks screwed down to the uprights.

The frame is so arranged that the upper segment shall be as light as possible. When the panel frame is upright the lower segment has two points of support, the axis of rotation and the cill: the upper segment on the other hand has only one, the axis of rotation; it is, therefore, exposed to the heaviest pressure.

The uprights are each 5·5″ × 5·116″ near the axis of rotation, diminishing to 3·93″ × 5·116″ near the head of the upper segment; the top and bottom pieces are attached to the uprights by iron straps.

To render the upper segment as light as possible, the uprights are not continued to the extremity; they are made only 5 feet 5 inches long, the

cross head piece being crowned by a top piece, kept in place by wooden brackets.

The frame work of the lower segment is strengthened by an iron strap which passes round the whole of the base. A handle is placed at the middle of the foot of the panel frame ; it is fixed on at its two extremities by bolts, and is further screwed down at the middle to the woodwork ; a slight curve has been given to it, to facilitate the operation connected with raising the panels. The employment of iron instead of wood has been discussed,—the use of wood enables the panel frame to be made lighter; the entire weight also is removed during immersion; but iron ensures greater duration, allows of a less thickness, and thus by necessitating more simple arrangements as regards the cill and flooring, diminishes one force it is necessary to overcome in raising a panel, viz., the pressure due to the shock of water against the foot of the lower leaf.

*Counterpoise of the panel frame.*—The weights of the upper and lower segment are nearly the same; when, however, the latter is immersed in the water, its weight is destroyed, so that the weight of the upper segment is an obstacle to the lowering of the under segment; counterweights, therefore, of iron of 145·46 lbs. are attached to the uprights of the panel frame. [*Plate* II., *Figs.* 5, 9 *and* 11.]

*Spur brace.*—There are three parts in every spur brace—the head, body and foot. [*Plate* II., *Figs.* 1, 2 *and* 10.]

The head of the spur brace is wide and flat on its two vertical faces ; its thickness is ·3·54 inches at the junction with the body, and 4·72 inches at the articulation of the jointed arm.

This articulation is composed of two vertical jaws, welded on the middle of the head of the jointed arm ; the head of the spur brace penetrates between these jaws and is fixed by a 2-inch iron pin.

The shape of the jaws of the articulation and the curve of the head of the spur brace are fixed in accordance with the two following conditions :—

1st. The woodwork of the panel frame must turn on its axis of rotation without interfering with the articulation.

2nd. The space between the jointed arm and spur brace when laid flat on the floor, on the prolongation of one another, on the one side, and between the check plate of the spur brace and the flooring, on the other side, must be sufficiently large to enable the sliding bar to move freely. The

second bolt connecting the jaws and the head of the articulation is countersunk.

The head of the spur brace is so arranged as to move transversely on this pin between the jaws of the articulation, but only in one direction, viz., on the side of the escape guide attached to the check plate. To do this, the eye of the head of the spur brace is widened.

The body of the spur brace is a cylinder 3·54 inches in diameter, carrying a ring near to its junction with the foot. This ring is used sometimes to attach a hook to, when it is desirable to lower the panel. To do so, the sluice-keeper proceeds to the down-stream side of the dam; he then, by means of an iron hook fitted to a long wooden handle, seizes the spur brace, and draws it to the side of the escape guide in a direction oblique to the current; this operation is sometimes necessary when repairs to the dam are being carried out, or when sand or other foreign matters, having collected in the angle formed by the front and sole of the check plate, prevent the spur brace from meeting the tongue or catch of the sliding bar. The foot of the spur brace is in a long handle-like shape, flattened to the extremity so as to fit close against the front and sole of the check plate. The form given to this part has been determined by experience, thus—

The spur braces of the panels at the dam of Conplans are $2\frac{3}{4}$ inches iron rods, nearly cylindrical from head to foot.

When the panel frames of the navigable pass are raised under a considerable head of water ($2\frac{1}{4}$), the current strikes the spur brace with so much force as to hold it suspended in the water; to counteract this, an addition of 22 lbs. has been made to its weight.

The foot of the spur brace is shaped to an angle of 3 degrees on the side of the escape guide.

The total length of the spur brace is 8 feet 10·2 inches. It forms, when in place, the hypothenuse of a right-angled triangle, whose shorter side is the length of the upright of the jointed arms, and the longer that same length increased by the breadth of the chamber contrived for the sliding bar and the foot of the spur brace. In such a position, the spur brace makes an angle of 52° 50′ feet with the vertical.

*Check plate of the spur brace.*—It has been explained that when the panel frame is being lowered, the spur brace must slide along in the down-stream direction, and that when the panel frame is raised, it must abut against the front of the check plate; these movements must be performed

with perfect precision. To effect this, a piece of iron is cast of the following dimensions and shape :—[A A, *Plate* II., *Figs.* 2 *and* 3.]

It is inclined in plan, and of a trapezoidal form, 1 foot 4·5 inches long, 9·4 inches broad at one end, and 4 inches at the other; along the sloping faces thus formed are raised rims or flanges 1·18 inches thick and 2·36 inches high. On the side of the panels, this block of iron presents a front of 4 inches in height and 4·7 inches in breadth. The space in front of the block is enclosed on one side by a raised rim similar to those on the sloping faces but inclined at an angle of 45 degrees, and on the other side by the escape guide BB, which itself is provided with a raised margin 2·36 inches high.

The sole of the check is between the inclined flange and that of the escape guide; it extends as far as the beam which carries the sliding bar, its breadth is 1 foot 5·3 inches. The total length of the escape guide is 5 feet; its breadth has not been absolutely fixed, but it must not, including the flange, be less than 6·7 inches—the escape guide is curved.

The front of the inclined plane slopes at an angle of 3 degrees towards the escape guide.

The inclined plane and escape guide are cast in two pieces, but are joined together and fixed down on the flooring by iron cramps.

The check plate is so placed that the middle of the inclined plane and the middle of the extremity of the escape guide are on the projection of a plane normal to the panel frame and passing through the axis of the spur brace.

When a panel is to be lowered or raised, the following is the process :—

When the spur brace is drawn in the direction of the angle of escape, it glides along the front of the check plate as far as the rounded angle which terminates it; there losing all support, it escapes into the guide along which it continues, sliding along by the flange till it is completely level on the floor; in that condition its axis lies over the centre of the inclined plane; and, consequently, under the axis of the panel frame which lies flat above; such being the case, everything is in readiness for the operation of raising. When the panel is being raised, the foot of the spur brace follows the middle line of the inclined plane; it hardly ever inclines to the escape guide, and cannot, from the construction, pass towards the other side; further, to insure this movement, a groove has been cut both in the iron and in the stones of the flooring; it, consequently, arrives between

the two flanges of the inclined plane which guide it in its ascent. When arrived at the extremity of its course, it falls sharply to the sole of the check, and is held there the more strongly in proportion as the pressure of the water on the panel is greater.

The prolongation, at an angle of 45 degrees, of one of the flanges of the inclined plane, keeps the spur brace from moving in that direction, should the panel experience any shock, &c. The front of the check plate is not a vertical plane; it makes an angle of 107 degrees with the sole. This arrangement has been adopted with a view of reducing as much as possible the space which the foot of the spur brace must traverse after falling over on that sole, in order to come back against the front of the check plate.

The angle of escape fixed for the frout of the check plate is 3 degrees, experience having proved it to be the best. The sole of the check should have an angle of escape nearly similar.

*Sliding tongued bars.*—The sliding bar is the piece of machinery which causes the spur brace to move along the front of the check plate, and draws it into the escape guide. It is a flat bar, armed with as many projecting pieces or tongues as there are spur braces to lower it; it is set in motion horizontally and parallel to the flooring, by means of a crab winch placed at one extremity of the navigable pass. [*c c c*, *Plate* II., *Fig.* 2.]

This crab winch acts on a horizontal rack welded to the end of the sliding bar.

When the breadth of the navigable pass exceeds 100 feet, the bar is generally divided into two parts, placed end to end; each is worked in the opposite direction to the other by means of a crab winch, placed, one on the right the other on the left, of the navigable pass. The end of each bar enters a chamber made for the purpose in the wingwall or pier which limits the navigable pass at the sides. The different parts of the machinery connected with the sliding bar are—

(1). The bar itself outside the wingwall into which it slides.
(2). The guides or races.
(3). The supports.
(4). The part of the bar which enters the wingwall.
(5). The chamber of the crab-winch.
(6). The crab-winch itself.
(7). The tongues of the bar and their distance apart.

*The bar.*—The bar is supported by movable guide rollers, and kept in

position by iron guide rails; these rails, as well as the supports, are screwed on to a beam of wood fixed in a groove of the flooring by gudgeons; these are fastened to the stone and screwed down to the wood. The bar is 1·97 and 1·18 inches thick on the side of the spur brace. [*Plate* II., *Fig.* 2.]

It carries below some clamps, 2·36 inches broad, 1·18 inches thick, and at least 4·72 long; these penetrate between the guide rails; each clamp is pierced at its lower part by a hole intended to receive a pin, when it is considered advisable to diminish the play of the bar between the guide rails.

The different parts of the bar are welded together, so that they may be easily taken to pieces and rejoined when necessary.

The two sliding bars of a navigable pass are generally of unequal lengths; the shortest lowers the first panels one by one; these panels are those which offer the principal resistance when the difference between the level of the water on the two sides of the dam is a maximum. In proportion as the number of panels lowered increases, the difference of level, and, consequently, the resistance, diminishes, so that the lowered bar can act on two panels at a time, then on three, or even on four, without the guard being compelled to exercise much effort. The smaller bar is, therefore, placed on that side which is nearest the channel through which the navigation of the river takes place.

*Guides.*—The guides or guide rails are two horizontal and parallel flanges of iron, 4 feet 11 inches long, and 1 inch in diameter; they are kept in their place by hold-fasts screwed on the wooden beam which carries the sliding bar. The rails are sufficiently raised above this beam to allow of sand and gravel passing underneath. [*Plate* II., *Fig.* 13.]

The slide bed is so arranged that the clamp supported by the two guide rails is raised between 3-10ths and 4-10ths of an inch above the beam, and remains always fixed between the rails during the movement backwards and forwards of the sliding bar.

The guide rails should direct, but not support, the sliding bar; consequently, there remains below it a play of about one-fifth of an inch.

The guides are 13 feet 1·4 inches long.

*Guide rollers.*—The sliding bar is supported on brass rollers placed 8 feet 6·3 inches apart, viz., double the breadth of a panel frame. Two of these rollers are always placed at the extremities of each guide, and are slightly raised above it. Each roller consists of a cylinder 4 inches

long and 2 inches in diameter, terminated by two pivots supported in half collars; these half collars are of cast-iron, and are screwed down to the beam in the flooring of the dam.

*The racked end of the bar.*—The sliding bar enters about 8 feet 10·2 inches into the wing wall, viz., 2 feet 3·5 inches into a recess which leads to the chamber where the crab-winch is placed, and 6 feet 6·7 inches into that chamber. The recess leading to the chamber is 7·8 inches high and 11·8 inches broad; it is closed by an iron door so pierced as to allow of the passage of the sliding bar. Immediately in rear of the door is a guide wheel which directs the bar against the pinion of the windlass. At the extremity of the bar is fixed, as we have previously stated, a rack 4 feet 7·1 inches long, with a clamp of the same length below. The rack is set in motion by the lower pinion of the axle of the crab, and the clamp moves in an iron guide. [*Plate* III., *Fig.* 13.]

The rack is pressed against the pinion by three vertical bronze guide wheels, of which two are placed on the socket just-mentioned, and the other 1 foot 7·7 inches from the end of the course traversed by the sliding bar.

To prevent any shifting of the machinery two straps are passed over the rack.

The assemblage, composed of four guide wheels, two straps, a guide, and its groove, is so combined that the sliding bar may always be set in motion with perfect regularity. The extremity of the bar is not supported by horizontal guide wheels; the last vertical guide wheel being furnished with a projection which extends sufficiently far underneath to prevent any tendency to bend.

*Chamber of the crab.*—The chamber is generally 6 feet 6·7 inches long, and 2 feet 7·5 inches broad; the descent to it is made by an iron ladder. [*Plate* III., *Fig.* 6.]

In order to prevent sand, &c., from clogging the machinery, and to allow of water being pumped out, the following arrangements are made:—

1st. The opening through which the sliding bar passes is closed by an iron door. [*Plate* III., *Fig.* 10.]

2nd. The gearing of the rack is placed on a platform, along which runs a drain: a slope is given to the platform, and its edge is chamfered, so that the sand brought in is thrown into the drain.

From time to time the chamber is pumped dry, and the drain cleaned out.

*Crab-winch.*—The crab is composed of two vertical trees, of a large wheel and two pinions. One acts on the large wheel, the other on the rack of the sliding bar. The trees are kept quite vertical by collars and tripods; the pinions and rack are of wrought-iron, the large wheel of cast-iron. The pinions are 4·7 inches in diameter, and the large wheel 3 feet 3·3 inches. Some alterations have been proposed owing to the necessity which has arisen in practice of exerting greater power, and of transmitting a slower motion to the machinery. [*Plate* III., *Figs.* 3, 6 *and* 11.]

A circular iron limb, 11·4 inches in diameter, is fixed round the axle of the upper pinion; this limb is fastened by four bolts to the plate which covers the chamber; it is 2 inches broad and $\frac{1}{8}$-inch thick. In this pinion an iron spindle is placed, which passes through the centre of an iron nave, having handle sockets hexagonally disposed, and so arranged as to make angles of 40° with the horizontal. The nave is 11·8 inches in diameter at the base, and rests on the limb just described. A ring is fixed to the top of the iron spindle, by means of which the nave can be lifted off and separated from the crab-winch. Each of the iron handle sockets of the nave is 4 inches deep, 2 inches in diameter at the diameter, and 2·36 inches at the top. A lever of ash, 3 feet 7·3 inches long, and from 2 inches to $2\frac{1}{3}$ inches in diameter, slightly swelling in the middle, is placed in each socket. The nave thus armed with its levers, forms a kind of wheel whose horizontal projection is about 6 feet 6·7 inches in diameter. The sluice-keeper seizes the end of the levers, drawing with one hand and pushing with the other, without altering his position.

Experience has shown that two men can exert all their power on the windlass fitted with this key, but that three men bend the axle and break the lower pinion; so that more than two should never be allowed to work the machinery.

*Tongues of the sliding bar.*—The tongues of the bar project 3·93 inches, and are 1·18 inches thick, and 2·36 inches broad. A curve connects them with the line of the bar; thus formed, they bite about 3·4 inches of the foot of the spur brace. [*d d*, *Plate* II., *Fig.* 2.]

*Course traversed by the sliding bar.*—The course traversed by the bar must be less than the interval between two adjoining spur braces, and as that course is only the sum of the paths traversed by each of its tongues, it follows that the paths must be calculated in such a way that their sum total shall be less than the interval between the spur braces; it is also con-

venient to reserve a certain play for the first and last spur brace. An example will explain this latter.

Theoretically, the course of a tongue is equal to the breadth of the front of the check plate, which in the Seine dams is 4·7 inches; so that at the dam of Port à l'Anglais, whose pass, 179·4 feet long, is closed by 42 panels, the course of the sliding bar, supposing there to be only one, would be 42 $\times$ 4·7 = 16·5; but as the distance between the axis of the spur braces is only 4 feet 3·1 inches, and from spur brace to spur brace 3 feet 11·5 inches, the working of the bar would become impossible, since a tongue must pass under three spur braces before reaching the one which corresponds to it. Consequently, the distance traversed by the bar must be less than 3 feet 11·5 inches—this is managed as follows :—

1st. Two bars are placed end to end, these work in opposite directions.

2nd. The course of each tongue is reduced from 4·7 inches to 3·15 inches, by rounding the angle of the check plate next to the escape guide, and also rounding that angle of the foot of the spur brace opposed to it.

3rd. The tongues are so spaced that the first panels, viz., those subjected to the greatest pressure, can be lowered one by one, the next two by two, and the last, three by three. In the example we have taken, the dam of Port à l'Anglais, there are two bars—

| | | |
|---|---|---|
| The smaller commands | 20 | panels. |
| The larger ,, | 22 | ,, |
| Total, .. | 42 | |

The smaller lowers seven panels, one by one—

| | | feet. |
|---|---|---|
| The course traversed is 7 $\times$ ·2624 feet, | ... ... = | 1·8368 |
| The lower 4, two by two, the course traversed = $\frac{4 \times \cdot 2624}{2}$ | = | ·5248 |
| The lower 9, three by three, the course traversed = $\frac{9 \times \cdot 2624}{3}$ | = | ·7872 |
| Total, ... | = | 3·1488 |

Add for the play between the first spur brace and its tongue—

| | |
|---|---|
| For the interval left between the ends of the bars, ... ... } For the course of the last tongue, ... ... ... ... } | 0·4592 |
| Course traversed, ... | 3·608 |

The great bar lowers :—

| | | |
|---|---|---|
| 6 panels, one by one, | ... ... ... ... ... ... | 1·5744 |
| 4 „ two by two, | ... ... ... ... ... ... | ·5248 |
| 12 „ three by three, | ... ... ... ... ... ... | 1·0496 |
| | | 3·1488 |
| | Add for the play as before, ... | 0·4592 |
| | Total course traversed, ... | 3·608 |

*Intervals between the extremities of the two sliding bars of the same pass.*—It now remains to show how the ends of the two bars can be placed so as not to injure one another, in the interval of 3 feet 11·5 inches between the two spur braces.

In order to arrange for the lodging of the two ends, it is not sufficient that the bars should work in opposite directions; care must further be taken that, supposing the lesser bar commences by lowering the spur brace of the panel nearest its wingwall, the greater bar should be able to lower the first spur brace, that removed furthest from its wingwall, and, consequently, the last that nearest to the wingwall. Suppose, this condition being allowed, that

1st. The two bars are so acted on by their crab winches as to be ready to lower the spur braces.

2nd. Each of the last tongues is 2·36 inches broad.

3rd. The play between the first tongue of the lesser bar and its spur brace is 2·75 inches.

4th. The play between the last tongue of the greater bar and the corresponding spur brace is 2·75 inches.

It is found that the lesser bar passes beyond its last spur brace :—

| | | feet. |
|---|---|---|
| Play between the first tongue and its spur brace, | ... ... | 0·2296 |
| For 6 courses $6 \times \cdot 2624$, | ... ... ... ... ... ... | 1·5744 |
| „ 4 „ $4 \times \cdot 1312$, | ... ... ... ... ... ... | 0·5248 |
| „ 9 „ $9 \times \frac{\cdot 2624}{3}$ | ... ... ... ... ... ... | 0·7872 |
| Thickness of the last tongue, | ... ... ... ... ... | 0·1968 |
| | Total, ... | 3·3128 |

Similarly in the cases of the greater bar it passes beyond its last spur brace :—

| | | |
|---|---|---|
| Play between the last tongue and its spur brace, | ... ... | 0·2296 |
| Thickness of the last tongue, | ... ... ... ... ... | ·1968 |
| | | 0·4264 |

| | |
|---|---|
| The ends of the two bars united form a length of, ... | ... 3·7392 |
| As the interval between the spur braces is, ... ... | ... 3·9688 |
| The interval between the extremities of the two bars, ... | ... ·2296 |

The problem is therefore completely resolved.

*Spaces between the tongues on the bars.*—The tongues on the lesser bar are at variable distances, according to the number of panels to be lowered. When they have to lower the panels singly, they are placed 4 feet 6·3 inches apart; when the panels are lowered in pairs, the tongues are in groups of two, each group being separated 4 feet 6·3 inches from the next, but each tongue of the same group is only 4 feet 3·16 inches from its twin. When the panels are to be lowered in threes, each group is composed of three tongues; the tongues of the same group are 4 feet 3·16 inches from one another, but the groups are spaced 4 feet 6·3 inches apart.

On the greater bar, viz., the one which initiates the lowering at the spur brace, the furthest removed from its wingwall, the distances between the tongues are 3 feet 11·2 inches, increasing by a regular progression towards the wingwall.

*Indicator of the sliding bar.*—It is often necessary to know at any moment the position of the sliding bar and the panel on which it is acting. The indicator which supplies this information, and which for its simplicity has been used in the most recent dams, is made as follows:—

The upper end of the axle of the crab winch is terminated by a "carré," which exceeds by a few inches the iron plate covering the chamber. On this "carré," the vertical iron socket of an iron rod is placed; this rod, at a few inches above the covering plate, curves into a horizontal position—the horizontal index carries a grooved wheel, so arranged as to travel on a rail describing an Archimedean spiral, and at the same time to slide along the index whilst it turns with the axle of the windlass; the position of the wheel on the spiral indicates the position of the sliding bar, and figures placed where required, point out the number of the panel attacked at the moment the wheel is passing over them.

*Time employed in lowering a navigable pass.*—The time required to open a navigable pass is very short, and sensibly the same, no matter what the head of water may be; experience has also shown that the long bar lowers 25 panels as well as a smaller number.

From a series of experiments carried on at the dam of Melun in July 1865, the following results were obtained :—

A length of 192·21 feet of the navigable pass was opened on 4th July in 7 min.

| | | | | | |
|---|---|---|---|---|---|
| ,, | ,, | ,, | 7 | ,, | 5 |
| ,, | ,, | ,, | 11 | ,, | 5 |
| ,, | ,, | ,, | 14 | ,, | 4 |
| | | | Mean, .. | | 5 min. 15 sec. |

or, one foot in 1·63 seconds.

The greatest head under which dams in actual existence have been opened is in the case of these on the Upper Seine as follows :—

| | | | |
|---|---|---|---|
| Varonnes, .. .. | 5·25 feet. | Les Vines eaux, .. | 8·04 feet. |
| La Madelene, .. | 7·31 ,, | La Citanguette, .. | 9·02 ,, |
| Champagne, .. .. | 8·23 ,, | Le Condray, .. .. | 7·41 ,, |
| Samois, .. .. | 6·85 ,, | Evry, .. .. .. | 8·89 ,, |
| La Cave, .. .. | 5·15 ,, | Eblon, .. .. | 7·02 ,, |
| Melun, .. .. .. | 6·99 ,, | Port à l'Anglais, .. | 7·74 ,, |

Ordinarily, the pressure on the dam is measured by the difference between the level of the water on the up-stream sides, but as the pressure is a function of the difference of the squares of the heights of the water, and as it also increases as the square of the velocity of the water, a less head may be accompanied by a greater pressure.

*Arrangements connected with the cill and the panels when laid flat on the flooring.*—It will have been seen, from the previous descriptions, that the sliding bar, as well as the articulation of the spur brace and jointed arm, are parts, which though simple, must be protected as much as possible from chances of accident. [*Plate* II., *Fig.* 1.]

To afford this protection the cill and panels are so arranged that the delicate portions of the machinery, when the panels lie flat on the flooring are, so to speak, inclosed in a recess.

In the first place, the wooden cill, furnished with an iron check plate, protects the panels which, when flat, lie below the level of its crest.

In the second place, the cill forms a screen which stops the sand in its march, and prevents it passing under the panels.

It is true the sand carried along by the current rises over the cill, and falls into the space between the cill and the foot of the panel; but the quantity is small, and the open space is reduced to the least possible, consistent with the dimensions necessary for the proper working of the machinery; it is only 3·93 inches at its greatest breadth.

When a boat passes over the cill of a dam, it generally creates a slight afflux of the water, and sometimes grounding on the lower part of the flooring, strikes the panels, causing a certain amount of oscillation; this has been reduced by giving three points of support to every important piece of the machinery. Thus, the panel frame rests on its axis of rotation, the spur brace, and jointed arm; the jointed arm rests on its sockets, the flooring and the spur brace; the spur brace rests on the jointed arm, the flooring and is kept in its place between the flanges of the check plate.

*Spaces between the panels.*—The sand carried along above the cill of the dam rolls against the panel frames and falls backwards. Some, however, finds its way in the spaces between every two panels. To suppress the space is the only means of stopping this, and such is impossible as the machinery could not be worked. In the dam of Conflans, the intervals were fixed at 2 inches, but were afterwards reduced to 1 inch by planks nailed on the faces of the panel frames. In the more recently constructed dams on the Upper Seine, the spaces have been increased to 4 inches.

*Raising the panels.*—The panels of the navigable pass are raised, one by one, by the aid of a crab-winch placed on a boat. [*Plate* III., *Figs.* 1, 2, 7, 8 *and* 9.]

The sluice-keeper standing at the bow of the boat, seizes with a long iron hook the foot of the panel frame; this hook is attached to a rope passing through a pulley, and wound round the crab. As soon as the panel frame is hooked—the winch is turned, the rope winds up, and the foot of the panel frame rises with its jointed arm and spur brace. By degrees all the pieces arrive at the position they are to occupy in order to support the axis of rotation—the panel frame then remains suspended nearly horizontally on this axis—the counterpoise causes the lower leaf to fall, and the pressure of the water tends to force it against the cill; but its movement is moderated, by slowly unrolling the rope attached to the hook. When the lower leaf rests against the cill and the panel consequently is upright—the hook is detached—and a test is applied to the spur brace to ascertain if the foot is well home against the check plate.

The time taken to raise a panel has been determined by a number of experiments on the nine following dams:—

| | | | min. | sec. |
|---|---|---|---|---|
| Conflans, panels, | 7·54 feet × 3·608 feet | ... | 1 | 30 each panel. |
| Beaulieu, „ | 7·87 „ × 3·936 „ | ... | 2 | 13 „ |
| Varennes, „ | 9·84 „ × 3·936 „ | ... | 1 | 58 „ |

| | | | | min. | sec. | |
|---|---|---|---|---|---|---|
| Samois, panels, | ... | ... | ... | 1 | 30 | each panel. |
| Champagne, „ | ... | ... | ... | 2 | 0 | „ |
| La Cave, „ | ... | ... | ... | 3 | 25 | „ |
| Melun, „ | ... | ... | ... | 2 | 26 | „ |
| Condray, „ | ... | ... | ... | 1 | 46 | „ |
| Evry, „ | ... | ... | ... | 2 | 11 | „ |

The raising of the panels first described involves several successive operations—the details of which it will be convenient to consider under the following heads:—

The boat and its fittings.

The anchoring and working of the boat.

The hooking on to the foot of the panel frame and the raising up of the panels.

The testing whether the foot of the spur brace is in its proper place.

*The boat and its fittings.*—The boat must be made solidly and of sufficient size to allow the workmen to move about freely; it must be capable of carrying all the tools necessary for working the machinery of the dam, and duplicate portions of the delicate parts, so that urgent repairs may be made without unnecessary delay. It is of oak, and well bulwarked. Angle irons are employed to strengthen the gunwale; the breadth between the bulwark is 7 feet 2·6 inches; the total length, including the bow (whose deck is 6 feet 6·7 inches long) is 26 feet 2·9 inches. [*Plate* III., *Figs.* 1, 2, 8 *and* 9.]

A crab-winch, composed of two large wheels, two pinions and a winch, is placed as the end of the boat in such a way as to increase its strength. The wheels are each 1 foot 11·6 inches in diameter. The crab-winch is furnished with a catch to stop its motion at any moment, and with a click to allow of the rope being unrolled during the operation of lowering the lower segment of the panel frame. The crab-winch is, in recent works, made, entirely of iron, and so constructed that, by a slight horizontal movement of the axle, one of the pinions can be thrown out of gear, one pinion only being required when the first panels are raised, whilst two are necessary in the subsequent operations.

The boat carries at its stern an iron ring and hook to which the rope can be attached.

This rope is looped at every 4 feet 3·16 inches, that being the breadth of each panel and intermediate space. In the regulating weir, this is increased to 4 feet 7 inches.

A large pulley is placed at the bow of the boat so arranged as to take a position in the line of traction; it is fitted with iron supports and completed by the addition of two guide wheels, one horizontal, the other vertical, which keep the rope on the groove: near this pulley, and quite disconnected from it, is placed an iron hook fitted with a long handle. The traction rope attached to this hook passes through the pulley and round the barrel of the crab.

*Fender frames.*—In order to keep the boat parallel to the panels when any operations are being performed, two frames are attached to the side, one near the bow the other at the stern; both are of open work, otherwise the force of the current would push the boat into that part of the pass intended to be closed. It is useful to have two sets of frames of different sizes, one set to be used when the water is low, the other when the water is high. [*Plate* III., *a*, *Fig.* 7.]

Each frame is furnished with a fender of wood, of such a length that the point of support which it affords to the boat on the raised panels should be below their axis of rotation.

The frames are so hinged on to the side of the boat as to allow of their being either entirely removed or merely folded back.

A service movable bridge placed over them enables the sluice-keeper to stand close to the panel frames on the down-stream side, and test whether the feet of the spur braces are home in their proper places.

*Keys.*—To keep the boat parallel to the panels, two T shaped iron keys are placed near the crab; there they are ready at hand for the man working the machinery. One of them, a rod of iron with a T head, is placed in a kind of recess in the side of the boat, which can be opened and shut at pleasure; the other is passed through a hole in the side of the boat below the first, and is made in two portions, which can be screwed together when required. [ *Plate* III., *d*, *Figs.* 2.]

The first is used when the river is in its low or medium stage; the second, when in its high stage.

In addition to these tools, the boat contains a duplicate rope, two traction hooks, an anchor, some hooks and boat hooks, a grease box, some hammers, turn screws, &c.

*Anchoring the boat.*—The boat must be considered in three different positions.

(1). When it is not in use.

(2). When it is employed in raising the first panels.

(3). When it is employed in raising those panels which are furthest removed from the channel of the navigable pass.

1st. When the boat is not in use, it is moored and padlocked in a basin close to a wingwall; all the tools are chained down or placed in store. During the winter floods the boat is covered with an awning. The basin is of sufficient size to contain two similar sized boats, and some smaller ones.

2nd. When the necessity arises for raising the first panels of the navigable pass, two cases must be distinguished.

(1). When the panels are near the wingwall close to the basin.

(2). When the panels are near the pier which connects the navigable pass and regulating weir.

In the first case, the boat is placed parallel to the wingwall, at a distance from it equal to half the breadth of a panel; and so moored in front, that a sufficient space is left for the panel frames, when raised, to revolve open on their axis of suspension; rings fastened to the wall assist in keeping the boat in position. Directly the fresh panel is raised, the boat is moved on a panel's breadth, in order to bring it to the middle of the second panel; it is then moored, and the second panel is raised. This is continued till the boat is so far removed from its basin as to render it necessary to find some point of support in front; one of the side fender frames is then put on.

When the panels to be raised are on the side of the pier which separates the navigable pass and regulating weir, the boat is placed across the starling made rectangular for the purpose, and furnished with ring bolts in the same way as the wingwall. The operations then proceed as in the former case.

If there is any fear lest the sheet of water passing over the regulating weir should affect the stability of the boat, the panels of the regulating weir nearest the pier are raised previous to operating by those of the navigable pass.

It may become necessary to raise the first panels without taking points of support for the boat on the wing-wall or pier; a series of supports must then be artificially created. This is simply done by the following contrivance:—

A spar of wood, between 30 and 40 feet long, is floated at a convenient

distance from the dam; a ring is attached to the foot which slides on an iron bar solidly let into the bank or into a stone near the panels to be raised; the iron bar is in a vertical plane parallel to the dam. The head of the spar is secured to a cable moored to a pile or ring fixed on the bank, and hooks are placed on this float at distances apart equal to the breadth of a panel. This premised, the procedure is as follows:—

(1). The spar of wood is placed parallel to the dam, and is moored in that position by the cable just mentioned.

(2). The stern of the boat is fastened to that one of the hooks which corresponds to the first panel to be raised, in such a way that the pulley at the bow of the boat is opposite the middle of the panel.

(3). The foot of the panel frame is hooked and raised.

(4). The boat is then pushed on a distance equal to the breadth of a panel, its stern being secured to one of the hooks; and so on, for the remaining panels.

(5). When the boat arrives at the end of the floating spar, sufficient panels have been raised to give the necessary points of support.

(6). The boat is then detached and moved towards the panels, the spar being taken back to the bank. The necessity may sometimes arise for commencing the closure of the navigable pass by raising those panels which are neither contiguous to the wing wall or pier; for instance, at the dam of Melun, the closure of the pass is commenced by raising the panels nearest the lock, in order that the rush of the current may be kept away from the side of the lock chamber. To accomplish this, the boat is merely moored by the stern to the rings fixed for the purpose in the upstream head of the lock.

At first, the position of the boat is nearly perpendicular to the dam, but becomes more and more inclined as the panels to be raised are at a greater distance from the lock head. It attains its greatest angle when the 7th panel (25 feet 7 inches from the lock) is being lifted. Experience has shown that these seven panels can be easily raised in 25 minutes, by the aid merely of the crab-winch and boat-hook.

When six or seven panels have been raised, by taking the wingwall pier, &c., as points of support, the operations are continued by using these upright panels for the same purpose. The boat is placed parallel to the panels; and, consequently, perpendicular to the current. The fender

frames near the bow and stern are then pushed out, a T shaped key is placed in the space between the two adjoining panels above the axis of rotation, in such a manner that the T head is vertical; when this is done, the key is turned round till the T head is horizontal. The two frames and the T key perform the following functions.

When the foot of the panel frame is hooked, and pulled upon by turning the winch, the head of the boat is drawn towards the panel; this the bow frame prevents. If the hook or rope should break during the operations, the stern of the boat in the recoil would strike the panels—this is counteracted by the stern frame.

The tractive force, modified in its action by the frames, tends to force the boat along parallel to the dam in the direction of the panels yet to be raised—this is opposed by the T key.

*Seizing the foot of the panel frames and raising the panels.*—When the boat is in its proper place, the sluice-keeper plunges the iron hooked rod to the bottom of the water, and seizes the handle of the lower segment of the panel frame. This is performed very easily; the hook is pushed forward on the back of the panel frame and then drawn in the up-stream direction; in its course it falls into the hollow of the tail cross piece and catches in the handle. [*Plate* III., *Fig.* 2.]

When the panel is up, the hook is pushed down till it meets the flooring; it is then turned at right angles to its former position and thus easily withdrawn.

*Traction chains.*—The employment of an iron hook is simple when the head of water is not too great; but when that passes 1 foot 8 inches, the water exerts such a buoyant influence on the hook as to render it difficult for the sluice-keeper to push it down to the handle of the panel frame. To obviate this inconvenience, two chains are attached to each panel frame; one, 18 feet 4·4 inches long, is fastened to the handle of the lower segment; and the other, 1 foot 7·7 inches long, to a ring screwed into the top cross piece of the upper segment.

The panel frames are connected with one another by these chains, in such a manner that the head chain of one is linked to the foot chain of the next. Supposing No. 1 panel frame to be raised; on its head is fastened the chain which is linked to the foot of panel frame No. 2; when No. 2 is lifted up, it brings up the chain attached to the foot of No. 3, and so on. The sluice-keeper detaches the chain of No. 2 from

No. 1, and fastens the traction cable to it; he then gives a few turns of the winch and raises No. 2, which brings up the chain of No. 3 with it.

At the dam of Conflans, it was only found necessary to attach chains to the last six or seven panels, as, in that part of the pass, the current engendered by the closure of the rest sweeps through with such force as to make it very difficult to use the iron traction hook.

An attempt to extend their use on the whole length of the navigable passes of the dams subsequently constructed, was not attended with satisfactory results, so that they are still limited to those panels which are raised last.

The inconveniences attending their use are as follows:—

(1). When a chain falls on the junction of the two sliding bars, it may get in under one of them, from whence it can only be removed by breaking.

(2). The chains placed in the part of the channel used, by boats—when passing through the navigable pass—are liable to be caught by the keels, and snapped; if they should be too strong for this, they tear away the woodwork.

(3). When the pass is being opened, the lower part of each chain should fall before the upper; consequently, if the panels are raised from right to left, they must be lowered from left to right; this being a condition not always possible to fulfil, the chain sometimes falls under the upper segment of the panel frame, from which position it can only be disengaged with considerable trouble when the pass is closed again.

The chains used in the first dams were sometimes broken—thus in December, 1864, at the dam of Ablon, three chains snapped, whilst the guard was raising the last three panels of the navigable pass under a head of water of 3 feet 11·2 inches. To prevent similar accidents, the links are now made of $\frac{3}{5}$-inch iron; a few chains with $\frac{4}{5}$-inch links being kept in stock for extraordinary cases, so that traction chains are only employed for a small number of panels.

*Dimensions of the fender frames.*—The lifting power exerted by the boat crab increases or diminishes in proportion to the distance it is placed from the panel; consequently, if the fender frames are too long and the water low, the lifting force exerted is small; if too short, the horizontal draw becomes stronger than the vertical pull. Their length has been fixed at 3 feet 3·3 inches for use, during the low and mean stages of the

river, and 4 feet 3·1 inches during the high stages—the breadths being respectively 4 feet 3 inches and 4 feet 11 inches.

*Verification of the correct placing of the spur braces.*—When a panel frame is raised, the foot of the spur brace ascends the inclined plane, and falling against the front of the check plate, rests at the middle point; but certain accidents may occur to prevent the spur brace taking this position.

1st. When the tractive force is exerted in the direction of the middle of the panel, the spur brace arrives properly in its place; but if the tractive force from any reason is brought to bear obliquely, the spur brace, in leaving the guides of the inclined plane, tends to move either to the right or left; if to the right, the flange prolonged from the inclined plane at an angle of 45 degrees sends it back to its place; but if to the left, on the side of the escape guide, it rests against the edge of the front of the check plate, and may be displaced by the slightest shock.

2nd. The same effect may be produced by the oscillations which the T key and two tender frames communicate to the panel frame when it is being raised. These oscillations are considerable in the first panels, but diminish as the pressure of the water increases, and cease completely when the head of water attains the height of 5 or 6 inches.

3rd. Sand or gravel sometimes collects in front of the check.

It becomes, therefore, of great importance to ascertain the exact position of the spur braces, and to rectify it if necessary.

To do this, the sluice-keeper mounts on the service bridge, and verifies, by means of a boat-hook, the position of the spur brace; when he finds it too close to the escape guide, he pushes it with the hook in the opposite direction. Although the sluice-keeper is not well placed, and works with a tool having a flexible handle, the operation is easily and without much effort performed, so long as the head of water produced by the panels does not exceed 8 inches; above that the operation is useless, for the spur brace acted on by the current engendered under the panel frame during the process of raising, generally falls well into its place, and the oscillations which would tend to move it out again do not arise. When the spur braces are in place, the whole of the panel frames must be exactly in line, if not, it is a proof that the dam is badly raised. The sluice-keeper has to make the necessary alteration.

If, notwithstanding every precaution, a spur brace does escape, and the panel fall, the sluice-keeper takes the boat and raises it again.

*Head of water under which the navigable passes are closed.*—When the first panels of the pass are being raised, the head is almost imperceptible, but it increases as the debouch diminishes, and attains its maximum when the last panels are being lifted.

The maximum head when the last panel was being raised is given for different dams in the following table :—

| | | | | | | |
|---|---|---|---|---|---|---|
| Conflans, ... | 3·08 | feet. | La Cave, ... | ... | 4·198 | feet. |
| Varennes, ... | 3·28 | „ | Melun, ... | ... | 3·67 | „ |
| Champagne, ... | 3·706 | „ | Evry, ... | ... | 3·968 | „ |
| Samois, ... | 3·28 | „ | Ablon, ... | ... | 3 936 | „ |

*Self-acting panels.—Properties of self-acting panels.*—A self-acting panel does not differ in form from those already described; it is always a frame of carpentry turning on a horizontal axis, which axis rests on fixed supports or on a movable jointed arm and spur brace. Such a panel has two essential properties; it opens of its own accord by turning on its axis of rotation, when the water on the up-stream side attains a certain height, and recovers its upright position by returning on its axis when the difference of level between the head and tail water is reduced to a certain limit.

This last property has to be moderated, as too rapid a closure would precipitate a rush of water down the navigable pass and prevent the raising of its panels.

*Description of a regulating weir on the Upper Seine.*—The fixed part is composed of two frames of wood, consisting of main and sheet piles, 14 feet 3·5 inches apart, braced solidly together along the whole length, and tied across by as many beams as there are panels.

A strong double cill, bolted down with angle irons, consolidates the whole, keeps the cross beams in position and forms the support against which the panel frames abut.

As soon as the framework is fixed on the bottom of the river, either being driven in, as in the case of the piles and sheet piles, if the bed admits, or cramped with iron to the rock, if such presents itself; a mixture of gravel and stones is thrown between, and covered with a mass of béton, poured in for a depth of 5 feet. The béton is then protected by a pavement of cut stone or a platform of wood nailed to the framework. The platform is used where the water rises to too great a height to permit of the flooring being fixed without pumping.

On the up-stream side, earth or sand is heaped against the wood work to the level of the top brace. On the down-stream side, an apron of large

stones is necessary to withstand the scouring action of the overflowing sheet of water.

*Details of the different parts of a self-acting panel.*—The panel frame rests against a cell, fastened to the cross beam by angle irons, by an iron check plate, and by long straps of iron; all are screwed down to the woodwork. Each cross beam also supports a check plate and escape guide. Three consecutive cross beams carry, one, a guide for the sliding bar, the other two, a guide roller apiece; so that a guide and two guide rollers occur alternately. Each clamp of the tongued bars is 3 feet 11·2 inches long, so that it never leaves its guide; the course traversed by the sliding bar being only 3 feet 7·3 inches. The length of a guide is equal to the breadth of the cross beam. The collars of the foot of the jointed arm are screwed down to the woodwork. The spur braces, jointed arms, and collars of the panel frame are similar to those of the navigable pass. [*Plate* II., *Figs* 7 *and* 8.]

The articulations can be made in such a manner that the lateral play shall be either in the spur braces or in the jointed arms; the latter is the better arrangement.

The height of the movable part in the regulating weir being less than in the navigable pass, and the pressure of the water in consequence being diminished, the dimensions of the iron work are reduced, so that the spur brace is 2·36 inches in diameter, and the uprights of the jointed arm 1·97 inches × 1·57 inches.

A movable counterpoise is attached to each panel. It consists of a block of iron, pierced with a hole in the middle, by means of which it moves easily along a bar fixed on the back of the panel frame for the purpose. At each extremity, it is grooved on the under side, so as to slide on two guide rails. This counterweight can be fixed by means of a catch.

*Determination of the height of the jointed arms of the self-acting panels.*—Experience has suggested the following arrangements:—1st. The upper segment should diminish from the axis of rotation up to the head cross piece.

2nd. The centre of gravity of the lower segment should be removed as far as possible from the axis of rotation.

3rd. The axis of rotation should be placed a few inches above one-third of the total height of the panel frame.

4th. The breadth of the lower segment may be made a little greater than that of the upper.

On the Seine, the three first suggestions have been carried out, viz., the upper segment is diminished in thickness at its head; the lower segment is furnished with counter-weights, a fixed one, weighing 149 lbs., and a movable one of 70 lbs.—the axis of rotation is fixed a little above one-third of the height of the panel frame, but the 4th has not been considered necessary.

The thickness of the uprights of the upper segment is 4·7 inches near the axis of rotation, reduced to 3·54 inches near the head. The axis of rotation is placed 2 feet 3·9 inches from the foot of the lower segment, and 4 feet 2·8 inches from the head of the upper segment.

*The conditions under which the panel frames will open and close, in both cases spontaneously.*—Experience has shown that the panel frames of the regulating weirs always open spontaneously when a depth of water of 5 or 6 inches is flowing over the crest. Even when the counterweights (219 lbs.) on the lower leaf were increased to 331 lbs., no sensible alteration has been observed.

When a panel frame lies open, its upper segment makes an angle of 15 degrees below the horizon—and its lower segment is weighted with a fixed counterpoise of 149 lbs., and a movable one of 70 lbs. On the Seine a series of experiments were conducted with the following results:—When a panel frame open in free air, without water on either side, was weighted with an additional fixed counterpoise of 59½ or 208½ lbs. in all, on its lower segment, and the movable one was fixed to the upper segment with an addition of 52½ lbs, or 122½ in all, the lower segment responded to a very slight pressure, and the panel frame returning on its axis rose upright. When the water stood on both sides of the dam to a height of from 2½ to 3¼ inches above the cill of the regulating weir, the panel frames always righted themselves; but, when there was a fall of water from the up-stream to the down-stream side, the water had to descend 3¼ feet below the standard level before the panel frames returned spontaneously to the upright position; and this was the case, no matter what increase was made to the weights of the counterpoises; thus the two counterweights (219 lbs.) were both fixed on the lower segment. Then an addition of 111 lbs. was made, and subsequently a still further increase of 115 lbs., or 445 lbs. in all, without any sensible difference being perceived.

This failure in sensibility would seriously affect the height of water in the reach above the dam, if all the panels were equally sensible. Though however, all are constructed on the same pattern, they do not open simultaneously. Some are exposed to the current, others have greater friction in their collars, &c., none are exactly in the same condition as their neighbours. When, therefore, the water flows over the closed weir in sufficient quantities, all the panels are on the point of opening; but one or two only do actually open: if the water continues to rise, one or two others open, and so on, till an equilibrium is established between the water discharged and the free passage afforded; then the rise of the water is suspended; those panel frames which are least sensible remain upright. It is, however, quite possible to imagine that a sudden exceptional rush of water may open nearly all the panel frames simultaneously, and it is further worthy of notice that a panel frame remaining open for a long time causes a rush of water which may cause a disastrous scour on the apron.

In order to resolve the question completely, arrangements are now made by which—1st. The panel frame open at an angle of 15 degrees below the horizontal can be forced upright when the water is standing at its normal level.

2nd. A certain number of the panel frames can spontaneously right themselves, when the water has not descended more than 5 or 6 inches below the normal level.

*Raising the panel frames by means of a screen.*—When a panel frame is open, and the water above the dam is at its normal level, the upper segment of the panel frame, being twice the length of the lower segment, is pressed down with great force and prevents the panel frame from rising. If, however, by means of a screen transversely placed, the flow of water in the upper segment is intercepted, the pressure is reduced to nothing; whilst that in the lower segment increases. M. Garceau has invented such a screen. It is applied in the following way:—When the water has fallen about a foot below the normal level, a boat can be moored without danger to the neighbouring panel, which is upright; the guard then mounting on the service bridge at the side of the boat, takes the screen by the handle, rests one side against the upright panel frame, and slides the other, keeping it vertical along the back of the open panel it is intended to raise; the screen, being attached to the boat by two ropes, resists the water, which, being no longer able to act on the upper segment, rises

above the lower and presses so heavily as to force upright the panel frame.

*Spontaneous rise of the panel frame when the water falls 5 or 6 inches below the normal level.*—The least angle it is necessary to give to the panel frames in order that they may rise spontaneously under different heads of water, was determined by a number of experiments carried out at the dam of Citanguette:—

| The depth the water was lowered below the normal level, such normal level being 7·87 feet above the summer level, or 6·232 above the cill of the regulating weir. | Minimum angle above the horizon which must be given to the upper leaf to enable it to rise spontaneously as the water lowers, according to the first column. | The depth the water was lowered below the normal level, such normal level being 7·87 feet above the summer level, or 6·232 above the cill of the regulating weir. | Minimum angle above the horizon which must be given to the upper leaf to enable it to rise spontaneously as the water lowers, according to the first column. |
|---|---|---|---|
| Feet. | Degrees. | Feet. | Degrees. |
| ·656 | 45 | 1·804 | 25 |
| ·820 | 41 | 1·968 | 22 |
| ·984 | 37 | 2·132 | 20 |
| 1·148 | 35 | 2·296 | 15 |
| 1·312 | 33 | 2·460 | 13 |
| 1·476 | 30 | 2·624 | 10 |
| 1·640 | 27 | | |

With these data, it is easy to fix the angle of the panel frames in such a way as to enable them to recover themselves when the water stands at any determined height. To effect this, one end of a chain is fixed to the flooring of the weir; it is then passed through a hole in the lower segment of the panel, and resting on the face, is attached to a ringbolt on the top of the upper segment.

To regulate the angle, the sluice-keeper first of all opens all the panels, adjusting the length of the chain so as to allow the panel frames to fall to an angle of 15 degrees below the horizon; this is the final limit. The movable counterpoise slides on the upper segment and keeps the panel frame open; the sluice-keeper then closes the pass, and having done so, returns to the regulating weir, where he places the whole of the panel frames upright by pressing them with his feet, at the same time fixing the movable counterpoise on each lower segment: returning by boat to

those panels which are furnished with the chains, he fixes these latter in such a way as to keep the panel frames at the inclination he wishes them to take; when they are to open simultaneously, usually it is sufficient to chain 15 or 20 panel frames of each regulating weir, taking care to select the most sensitive, or to render them so by enlarging their lower leaves, and thus make it certain that they will open first.

*Raising the panels from their position on the flooring.*—When it is necessary to raise the panels from the flooring, the operation is performed in the same way as in the navigable pass, by means of an iron hook; care must be taken that each spur brace is well home against the check plate. When the movable machinery is entirely raised, the sluice-keeper passes to the down-stream side in his boat, and closes the entrance to each escape guide with a piece of wood, so that no spur brace can, in the subsequent movements, slip from its resting place.

*Opening the panel frames on the raised panels.*—Two cases must be distinguished, according as the navigable pass is open or not.

If the pass is open, which occurs when a flush is caused, the boat can be placed on the up-stream side of the upright panel frames; the sluice-keeper attaches his hook to a ring fixed in the foot of each lower segment and turns the winch, or as there is only a slight head of water, he can seize the upper segment and draw it in the down-stream direction—his position during this operation will be in the boat on the flooring of the weir. If the pass is closed, there are different cases to be noticed. It has been stated that when the water is flowing on the top to a depth of 5 inches or 6 inches, the panel frames open spontaneously; consequently, a very slight effort is required to open a panel frame when the water is flowing over the crest; as the level lowers, the difficulty increases. To exercise this effort, therefore, from a boat which rests during the operation against the neighbouring panels, it is necessary that they should not open. As long as the water does not rise within 1 foot of the crest, it is possible to prevent this by using the fender frames, already described, as under such conditions they would extend about 8 inches below the axis of rotation. But when the water rises up to or above the crest, it would be manifestly imprudent to place the boats near the movable portions of the dam. To obviate this, and to bring the work under control, it has been proposed to add a set of iron frames about 8 feet high, placed 9 feet apart, capable of supporting a service bridge, by which free access can be

afforded along the whole work. These service bridges are adopted on the Marne, but not at present on the Seine. They are calculated to cost about £4 16*s.* 0*d.* the running foot, and as the regulating weirs are built on an average for £17 6*s.* 0*d.*, the total expense would not exceed £22 the foot run.

*Reclosing the panel frames.*—Whilst the navigable pass is being closed, it is necessary to keep the panel frames of the regulating weir open, to allow of a free passage for the water, so that after closing the navigable pass, the sluice-keeper must return and shut these panel frames. To do so he mounts on the pier, presses with a hook the lower segment of the nearest panel frame, and closes it; he then stands on two brackets fixed on the back of that panel frame, and presses the lower segment of the second panel frame with his foot, thereby bringing it to the upright position, and so on with all the rest. This is easily accomplished, even when the level of the water rises about 4 inches above the axis of rotation. When the water at the commencement is so high as to make it advisable to close the passage more quickly, and thus prevent any great further rise, the sluice-keeper works from one side, and employs an assistant to work towards him from the other side; when the water is too high to allow of either of these methods, a boat must be used, for the current striking under the lower segment of the open panel frame exerts too great a force to be overcome merely by the pressure of the sluice-keeper's foot. The boat is placed in the same position as when employed in raising the panels; the counterpoise, which is on the upper segment, is drawn by the hook to the lower segment, and a few turns of the winch pull the upper segment into the upright position. This operation takes 2 minutes for each panel frame, whilst the process with the foot requires only 2½ seconds.

*Lowering the panels on the flooring.*—The panels are seldom laid on the flooring; they may remain oscillating on their axis without presenting any serious obstacle to the flow of the river, except under two circumstances, viz., when the river, during heavy floods, brings down much floating matter,—as this is sure to collect round the pointed arms and contract the sectional area of the channel,—and when the river carries ice.

In the first projects, the lowering was intended to be performed by means of sliding bars, similar to those used in the navigable passes, but several inconveniences attend their use, thus—

The sliding bars exercise no influence on the panels if these panels are not strongly pressed by the water on the up-stream side. It often happens that the depth of water on the down-stream side of the flooring is not sufficient to deaden the shock of the falling panel.

When the flooring is dry, or only slightly covered, malevolent persons may utterly destroy the machinery in a very short space of time.

These considerations, therefore, have led to the rejection of sliding bars in the regulating weirs, and the adoption of the following method:—

Suppose the panels are to be lowered in consequence of a threatened flood, which has risen $6\frac{1}{2}$ feet above the summer level: the panel frames float nearly horizontally in the water, and the head of water is nearly effaced. The sluice-keeper approaches from the down-stream side in a small boat, and closes two or three of the panel frames; his object is to lower down flat the first of these panels; so attaching the boat by a hook to the second—he seizes with another hook the spur brace of the first—at the same time that his assistant, at a given signal, forces the boat against the edge of this panel; the shock causes a recoil which moves the foot of the spur brace from the check plate: the sluice-keeper then raising it with his hook directs it into the escape guide, the panel pressed by the current and hauled on, if necessary by the assistants, falls flat close to the boat, which is safe behind the second panel.

The fourth panel frame is then raised and the second panel laid flat, and so on with the others.

By this method a sluice-keeper and two assistants are able to lower a panel in 3 or 4 minutes.

We now propose to describe the method of executing the works, and their cost.

*Dredging.*—The first operation at the site of each work was to dredge out the soil to the level where the béton of the foundation was to rest, after which the frames intended to enclose the mass of the foundation were put in their proper position. If the enclosing frames are composed of main and sheet piles driven into the soil, and not of caissons merely resting on the ground, the dredgings may succeed the placing of the frames; by this means the amount of material to be excavated is very much reduced, but generally the space would be so confined as to necessitate the use of small dredges only capable of performing a limited amount of work. It has also been found useful to raise the gravel which would otherwise remain

on the outside of the enclosed space in order to replace it with puddle or some impermeable material, which, by preventing filtrations, will facilitate the pumping out of the water from the inside.

The dredges in general use were of 20 horse-power; each with its apparatus complete cost £2,400; it lasts from 12 to 20 years; it is attended by 16 iron boats, $\frac{1}{6}$-inch to $\frac{1}{4}$-inch thick, costing £120 a piece.

Each dredge required a crew of from 5 to 9 men, viz., the captain, who directed the working of the dredge, with a salary of £8 a month; an engineer, on £6 a month; a head boatman on £6, to superintend the working of the boat; and 2 to 6 men to work the windlass, &c.

The volume dredged in a day of 12 hours varied with the nature of the soil, the distance to which the material had to be carried, &c.; the maximum amount was 14,126 cubic feet, or 1177 cubic feet per hour, but the average of the whole work at the dam of Citanguette, for instance, did not exceed 643 feet per hour.

The price of dredging the soil, composed of ·93 parts of earth, sand and gravel, and ·07 parts of loose blocks of stone at a depth of 7 feet below the water surface, carrying the same a distance of 1837 feet, and there discharging it on a bank 5 feet above the water level, amounted *4s. 0·72d.* per 1000 cubic feet—divided as follows:—

| | £ | *s.* | *d.* |
|---|---|---|---|
| Supervision and labor, .. .. .. .. | 0 | 2 | 4·8 |
| Coal, tallow, oil rags, &c., .. .. .. .. | 0 | 0 | 4·0 |
| Maintenance and repairs, .. .. .. .. | 0 | 0 | 10·3 |
| Interest of borrowed money, .. .. .. .. | 0 | 0 | 5 6 |
| | 0 | 4 | 0·7 |

*Enclosing frames.*—After the dredging is completed, the frames of wood are placed in their intended position.

These frames are of two kinds.

Where the bottom is of gravel or clay, the frame is composed of main and sheet piles driven in the ordinary way, the bracing being sometimes fixed under, and sometimes above, the level of the water.

The sheet piles are sufficiently long to rise 4 feet 11 inches above the summer level, in such a way as to form one of the faces of the cofferdam during the construction of the work; after the removal of the cofferdams these piles are cut off level with the braces.

All the pile driving was done by steam power; the monkey weighed 1653 lbs; the fall varying between 1 foot 7·5 inches to 13 feet; the Engines were of 12 horse-power, and were mounted on boats.

The cost of such an engine with all its gear was fixed at £2000. The daily expense for a working day of 10 hours was calculated as follows:—

| | £ |
|---|---|
| Maintenance and repair of the machine, .. .. .. | 0·40 |
| " " boat, .. .. .. | 0·32 |
| Coal, 881½ lbs., .. .. .. .. .. .. .. | 0·64 |
| A carpenter, .. .. .. .. .. .. .. | 0·28 |
| A mechanic, .. .. .. .. .. .. .. | 0 32 |
| An engineer, &c., ... .. .. .. .. .. | 0·60 |
| A boatman, .. .. .. .. .. .. .. | 0·24 |
| Oil, &c, .. .. .. .. .. .. .. .. | 0·12 |
| | 2·92 |

or, £2 18*s*. 4·8*d*.

The time taken in fixing a pile varied from 8 to 30 minutes, the mean being 12 minutes; the time employed in driving the piles per running foot was extremely variable.

When, as was the case at the dams of Condray, Citanguette and Vives Eaux, rock too hard to be penetrated by piles is met with at a depth of 8 to 10 feet below the summer level, the rock must be carefully cleared, and the enclosing frame simply placed on it in the following manner:—

Caissons are constructed on land exactly of the shape it is intended to give to the enclosing cofferdam. One of the sides, made of oak, is vertical, and arranged so as to form the permanent frame after the masonry is completed; the other side, destined to be entirely removed with the cofferdam, is of white wood. The rock having been cleaned, the frames of these caissons are lowered on to the spot where the cofferdams are to be; then the planks forming the two sides of the caissons are slid down. The interior planks are of oak, those of the exterior of fir. The lower extremities rest on the rock; the upper rise 4 feet 3 inches above the summer level. The exterior uprights are tied across to the interior uprights of the same caisson by iron tie-rods. These are necessary to prevent the caisson from crushing under the pressure of the earth inside.

Each caisson has a length of from 16½ to 19½ feet, and is attached to the adjoining one by iron straps. The distance between the caissons is preserved during the pumping operations by horizontal struts resting on

one side against the up-stream caissons, and on the other side against the down-stream ones.

*Cofferdams.*—Where the foundation is on rock, 11½ feet or more below the summer level, the cofferdams rest directly on the rock. When the caissons are in place, all gravel on the surface of the rock which would allow the water to pass under the cofferdam is removed by a diver; the space between the planks, if any, is closed by boards nailed on, and puddle worked up previously is thrown in and well rammed. Cofferdams thus constructed have always perfectly succeeded; for instance, in laying the foundations of the pass of Condray, the surface of the rock on the bottom of the river was laid dry for a length of 193½ feet and breadth of 32 feet 9½ inches; and, notwithstanding, the head of water was between 14·5 to 16·5 feet, the foundation was easily kept clear by a small rotating pump driven by an engine of 5 horse-power. When the enclosure is formed of main and sheet piles driven into the soil, the latter being of gravel, &c., the cofferdams rest on béton previously poured in. It has already been stated that one of the sides of the cofferdam is formed of sheet piles, rising 4·25 feet above the summer level; the other is made with "horses," and planks of white wood penetrating some inches into the mass of béton, and fastened to the pile planks by braces above and ties below. The clay is then poured in over the béton.

*Pouring in the béton.*—The béton, whose depth should not exceed 6 or 7 feet, is sometimes poured in in one layer, sometimes in two; it is better perhaps to bring it up to, or a little below, the level which it is to have eventually, though the custom on the Seine dams was to pour in an excess quantity, and then cut it down as required.

*Pumping.—Letestu pump.*—At the dam of Evry, one of these pumps was placed on a boat and worked by an engine of 5 horse-power. The connections between the pump and steam engine cost as much as £48, and required constant repair. The pump itself can be worked by hand when necessary, and is easily repairable by a common artificer. The pump consists of two cylinders, 1 foot 3·7 inches in diameter and 3 feet 5·2 inches long; the pistons are joined by a connecting rod, and have a stroke of 11·8 inches; the safe number of strokes is 13 per minute, and the discharge was 27·68 cubic feet. The height to which the water was raised varied in every dam; the discharging troughs were always placed about 2 feet above the crest of the cofferdams, or about 6 feet 2·7 inches above

the summer level; but the level of the water inside the wells of those dams where béton was used was about 5 feet below the summer level, whilst where the foundation was of rock, this depth was increased to 11·5 feet; the height the water had to be raised, therefore, varied between 11 and 17½ feet. A Letestu pump, not including the hose, costs £71.

The hose is composed of—

An elbow in copper, 6·29 inches in diameter, costing £3 4s.

A straight tube of galvanized iron, 9 feet 10 inches long and 6·29 inches diameter, costing £4 16s.

A copper pipe, 9 feet 10 inches long and 6·29 inches in diameter, costing £10 16s. In both cases, these prices cover the expense of the connecting fittings at each extremity.

An air pipe of 6·29 inches in diameter, costing £1 4s.

At the dam of Vives Eaux, which is founded on rock, 9 feet 10 inches below the summer level, a varying number (5 to 8) of smaller sized Letestu pumps were used, worked by an engine of 8 horse-power, each cylinder was 11·8 inches in diameter, the stroke of the pistons was 11 inches, and the number of strokes per minute 16 to 18.

The contractor paid every expense, and received for each hour of effective work—

| | s. | d. |
|---|---|---|
| For 8 pumps, ... ... ... ... ... ... | 5 | 7 2 |
| „ 7 „ ... ... ... ... ... ... ... | 5 | 0·48 |
| „ 6 „ ... ... ... ... ... ... ... | 4 | 6·72 |
| „ 5 „ ... ... ... ... ... ... ... | 4 | 0 |

No sum was allowed during the time the machine was not at work.

Supposing that the actual work performed = 7-10ths of the nominal power, the expense of every 100 cubic feet of water raised was—

| | d. |
|---|---|
| With 8 pumps, ... ... ... ... .. .. | 0·72 |
| „ 7 „ ... ... ... ... ... ... ... | 0·74 |
| „ 6 „ ... ... ... ... ... ... ... | 0·79 |
| „ 5 „ ... ... ... ... ... ... ... | 0·84 |

raised, if the proportion of actual work to nominal power is increased to 8-10ths,

To 0·84 per 100 cubic feet with 8 pumps.
„ 0·86 „ „ „ 7 „
„ 0·91 „ „ „ 6 „
„ 0·96 „ „ „ 5 „

The greatest height the water was raised, amounted to 15 feet 5 inches, and the least to 10 feet 10 inches.

*M. Belleville's centrifugal pump.*—These pumps are those of the groyne system, improved by MM. Mâllo and Belleville: they consist of a small turbine with a horizontal axis of rotation, drawing up the water through a vertical pipe fitted with a valve at its lower extremity. The turbine is placed on the cofferdam. It carries on its axis a pulley. The steam engine is also placed on the cofferdam, and is connected with the pump by a strap passed round the pulley. The pipe and turbine must be filled with water previous to commencing work.

The pump used at the Condray dam cost £39 16*s.* 9·6*d.*; its discharge was measured when the difference of the level of the water in the excavation and the discharging trough was 9 feet 10 inches; the pulley of the engine was 36·2 inches in diameter, and made 125 turns in a minute; the pulley of the turbine was 10·24 inches in diameter, and made $125 \frac{36{\cdot}2}{10{\cdot}24} = 442$ revolutions per minute; it has been stated that, under these conditions, the pump discharged 116·54 cubic feet per minute, while the Letestu pump only emptied at its maximum 27·687 cubic feet. If the height to which the water was to be raised had not exceeded 3·25 feet, one engine of 5 horse-power could easily have driven two pumps. The cost of the centrifugal pump is about half of that of the Letestu pump—it discharges four times as much—works without friction—requires little repair—and is much less cumbersome. Care, however, has to be taken that the lower end of the pipe is always plunged in the water, and that the joints are all tight, as the least introduction of air tends to choke the pipes, an inconvenience not experienced in the Letestu pump.

*Farcot pump.*—This pump is said to discharge 294 cubic feet per minute; the one employed was driven by a 12 horse-power engine; a sum of 7*s.* 2·4*d.* was paid per hour of effective work: all expenses connected with the maintenance, working, and moving of the machine being borne by the contractor.

The discharge of 100 cubic feet of water only costs 0·49*d.*, a very favorable result as compared with that of the Letestu pump.

A smaller sized pump of similar design was bought, and performed all the pumping required at the dam of Port à l'Anglais.

The diameter of the cylinder was 1 foot 5·7 inches.

The stroke of the piston was 5 inches.

The volume engendered with a velocity of 70 strokes was 106·79 cubic feet per minute.

The price per 100 cubic feet was 1·49*d*. The pump was worked by a steam engine of 5 horse-power.

The pump, including the following adjuncts, cost at the manufactory £220.

2 iron pipes 8 feet 2·4 inches long × 8·16 inches in diameter.
1 ,, ,, 8 ,, 2·4 ,, ,, ,, ,, ,,
2 ,, ,, 3 ,, 3·3 ,, ,, ,, ,, ,,
2 copper pipes 9 feet 10 ,, ,, ,, ,, ,,
An iron air pipe pierced with holes.

The connecting strap for transmitting the movement is 6 inches broad.

This pump proved the best of all. It required hardly any repairs, the only ones being the renewals of the india rubber hinges of the valves ; its price is, however, very high, and its volume large, so that it would only be used under exceptional circumstances.

The following is a summary of the results :—

| Name of pump. | Prime cost. | Discharge c. ft. per second. | Cost per 100 c. ft. | Engine, horse-power. | Per horse-power. c. ft. |
|---|---|---|---|---|---|
| | £ | | | | |
| Letestu, .. .. | 91 | 276·87 | 0·72 | 1 | 27·687 |
| Belleville, .. .. | 39·84 | 116·54 | .. | 5 | 23·30 |
| Farcot (large),.. .. | .. | 294·58 | 0·49 | 12 | 24·52 |
| ,, (small), .. | 220 | 106·79 | 1 49 | 5 | 21·35 |

WEIGHTS OF THE MOVABLE PORTIONS OF A DAM.

| Kind of iron or metal. | Name of movable piece. | Navigable pass. | Regulating weir. |
|---|---|---|---|
| | | lbs. | lbs. |
| Wrought | A jointed arm, .. .. .. .. | 266 64 | 139·26 |
| | A spur brace, .. .. .. .. | 323·40 | 77·55 |
| | The upper collar of the jointed arm, .. | 33·30 | 22·77 |
| | The handle of the lower leaf or segment, .. | 11·66 | .. |
| | ,, ,, upper ,, .. | 5·28 | 5·94 |
| | ,, ,, lower ,, .. | 24·31 | 43·45 |
| | ,, ,, ,, ,, .. | 17 49 | 12 87 |
| | A double guide for the sliding bar, .. | 9·46 | .. |
| | A foot in length of the sliding bar, .. | 12 70 | .. |
| Cast | A lower socket of the jointed arm, .. | 94·60 | 23·10 |
| | The counterpoise of the lower leaf, .. | 71·72 | 148·94 |
| | The movable counterpoise, .. .. .. | 30·80 | 69·85 |
| | A check plate, .. .. .. .. | 191·84 | 61·38 |
| | An escape guide, .. .. .. .. | 194·92 | .. |
| Bronze | A guide wheel for the sliding bar, .. .. | 5·50 | .. |

### Cost of the works executed.

The total sum expended on each of the 12 dams on the Upper Seine was £32,936.

| | | £ | | £ s. d. | |
|---|---|---|---|---|---|
| The mean cost of the locks | = | 15,443 | or | 0 13 3·36 | per square foot. |
| ,, navigable passes | = | 6,252 | or | 37 8 4·8 | per foot run. |
| ,, regulating weirs | = | 3,680 | or | 17 6 2·4 | ,, |
| ,, piers | = | 1,568 | | | |
| ,, sluice-keeper's house, .. | = | 568 | | | |
| | | £27,551 | | | |

The four sluices in the lock, together with the valves of the aqueducts in the side walls, cost £91,642.

| Name of dam. | Length of pass. | Length of weir. | Navigable pass per running foot. | | | Regulating weir per running foot. | | |
|---|---|---|---|---|---|---|---|---|
| | | | Fixed part. | Movable part. | Total. | Fixed part. | Movable part. | Total. |
| | Feet. | Feet. | £ | £ | £ | £ | £ | £ |
| Varennes, .. .. | 132·5 | 197 78 | 26·10 | 8 65 | 34 75 | 9·66 | 4·18 | 13·84 |
| La Madeleine, .. | 132·5 | 197·78 | 24·45 | 8 65 | 33·10 | 11·86 | 4·18 | 16·04 |
| Champagne, .. .. | 149·56 | 197·78 | 31 048 | 13 50 | 44·548 | 15·41 | 7 63 | 23·04 |
| Samois, .. .. | 171·21 | 197·78 | 31·77 | 8·82 | 40 59 | 8 69 | 4·14 | 12·83 |
| La Cave, .. .. | 149·56 | 220·74 | 23·33 | 11·21 | 34·54 | 9·14 | 5·41 | 14·55 |
| Melun, .. .. | 213·53 | 147·60 | 31·07 | 11·68 | 42·75 | .. | .. | .. |
| Les Vives Eaux, .. | 162·36 | 211·56 | 37·35 | 9·79 | 47 14 | 11·62 | 3·35 | 14·97 |
| La Citanguette, .. | 162 36 | 211·56 | 27·81 | 8·41 | 36·22 | 18·21 | 4·52 | 22·73 |
| Le Condray, .. .. | 166·62 | 229 93 | 30 66 | 8·04 | 38·70 | 18·88 | 3·66 | 22·54 |
| Evry, .. .. | 166·62 | 229·93 | 21·10 | 8·32 | 29·42 | 7·01 | 6·01 | 13·02 |
| Ablon, .. .. | 179·41 | 229·93 | 25·91 | 9 87 | 35·78 | 14·50 | 5·51 | 20 01 |
| Le Port à l'Anglais, .. | 179·41 | 229·93 | 22 70 | 8·87 | 31·57 | 14·14 | 2 70 | 16·84 |
| Mean, .. .. | .. | .. | 27·77 | 9·65 | 37·42 | 12 64 | 4·67 | 17·31 |

## DETAILS OF THE EXPENSE OF A NAVIGABLE PASS (DAM OF CONFLANS) AND REGULATING WEIR.

| Description of work. | Navigable pass. | Regulating weir. | Remarks. |
|---|---|---|---|
| | £ | £ | *Navigable pass.* Feet, |
| Earth moving and dredging, | 87·19 | 22·20 | Length of navigable pass, 114·47 |
| Puddle for the coffer dams, &c., | 6·33 | .. | Breadth between piles, .. 27·88 |
| Wooden framing and panelling, .. .. | 488·46 | 425·56 | Depth of béton, .. .. 5·74 |
| | | | Number of panels, .. .. 29 |
| Pile work for navigation, temporary works, coffer-dams, .. .. | 278·53 | 57·76 | *Regulating weir.* |
| Masonry on béton, .. .. | 485·14 | 52·59 | Size of Panels, 7·708 × 3·608 |
| Masonry in different parts, .. | 362·37 | 48·16 | Length of regulating weir, 85·28 |
| Surface work and pointing, .. | 68·44 | 8·74 | Breadth between piles, .. 13·12 |
| Loose stone work, .. .. | 318·10 | 26·53 | Number of panels, .. 20 |
| Wrought-iron screw nails, .. | 36·05 | 192·15 | Size of panels, .. 4·36 × 3·936 |
| Drilled iron, .. .. .. | 15·23 | .. | |
| Cast-iron, .. .. .. | 126·22 | 28·74 | |
| Lead bronze, .. .. .. | 7·97 | .. | |
| Fixing, .. .. .. | 17·70 | .. | |
| Tarring, .. .. .. | 7·67 | 2·90 | |
| Filling in frames with broken stone, .. .. | .. | 16·98 | |
| Total, .. .. | 2629·50 | 862·30 | |

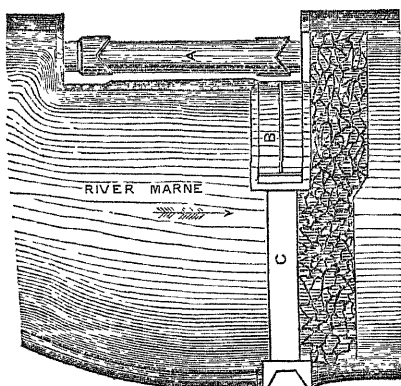
## DETAILS OF THE EXPENSE OF A PANEL (DAM OF CONFLANS).

| | £ | £ | |
|---|---|---|---|
| | | | *Navigable pass.* lbs. |
| Oak carpentry, .. .. | 1·058 | 0·844 | A panel frame weighs, 887·11 |
| Tarring, .. .. .. | 0·218 | 0·131 | Its spur brace, .. .. 176·32 |
| Wrought-iron fastened to the wood, .. .. | 1·480 | 2·353 | Jointed arm, .. .. 115·203 |
| | | | A socket, .. .. .. 52·896 |
| Wrought iron for all other pieces, .. .. | .. | 2·474 | *Regulating weir.* |
| Screws, .. .. .. | 0·264 | 0·233 | |
| Iron of the jointed arm and spur brace, .. .. | 4·761 | .. | A spur brace weighs, .. 37·468 |
| | | | Jointed arm, .. .. 59·948 |
| Socket bolts, .. .. .. | 0·218 | .. | Guide escape, .. .. 34·44 |
| Cast-iron of the sockets, .. | 0·768 | .. | |
| Cast-iron of the check plate and guide escape, .. | 1·431 | 0·520 | |
| Fixing a guide escape, .. | 0·480 | .. | |
| Iron of the counterpoise, .. | 0·385 | 0·580 | |
| Total, .. .. | 11·063 | 7·135 | |

The sliding bar cost £39·493, or 6s. 6*d.* per foot run. Windlass in the pier, &c., for moving the sliding bar cost £1,500.

Boat and its machinery cost £3,261.

M. DESFONTAINE'S SYSTEM OF MOVABLE PANELS FOR REGULATING WEIRS.

This system, invented in 1846 by M. Desfontaine, has been applied to several dams built on the Marne during the years 1863 to 1865. [*Plate* IV.]

A. Lock. B. Navigable pass. C. Regulating weir.

Each dam is 6 feet $10\frac{1}{2}$ inches high, and consists of—

1st. A submersible lock, 25 feet 7 inches broad and 167 feet 3·3 inches long, placed on the side of the river close to the towing-path.

2nd. A navigable pass, furnished with movable panels, similar to those adopted in M. Chanoine's system.

3rd. A regulating weir fitted with the peculiar panels which form the invention.

4th. A pier wingwall and other accessory works. Each navigable pass is 82 feet long, and is provided with 20 panels 3·11 inches broad, and varying in height at different dams from 8 feet 8 inches to 10 feet 2·5 inches. The cill of each, at first placed 1 foot 11·5 inches below the summer level, has been raised 2·75 inches by the application of a cill rail, which it was hoped would preserve the panels when laid flat on the flooring from injury.

The space left between each two contiguous panels is 2 inches; owing to the extreme accuracy now arrived at in planing masses of iron, this space has been further reduced in the most recent work to 0·4 inch, and it is confidently expected that it can be brought to 0·16 inch.

When the panels are upright their summit is 2 inches below the standard level of the water; consequently, there is an overflow of that depth, when that level is attained.

On the up-stream side of each navigable pass 20 iron frames, from 8 to 8 feet 10 inches, are placed; they can be laid down flat on the flooring in recesses prepared for them.

The objects of these frames are—

1st. To form a support for a service bridge at a height above the low water level of between 5 feet 6 inches to 6 feet 4 inches, along which the windlass used to raise the panels can be moved.

2nd. To receive, when the pass is closed, an additional height of from 2 feet 7 inches to 3 feet 4 inches, on which a second service bridge, raised 1 foot 7·66 inches above the normal water level is placed, to afford means of communication between the lock and pier.

3rd. To form a support for the movable barrier, composed of needles which we have described in M. Poireé's invention.

The division of each frame into two parts, placed one above the other, has a double advantage.

1st. The frames are at first lower; and, consequently, the space between the last one and the pier, as well as the recess to be arranged in the latter for receiving the head of the frames, is less.

2nd. The proximity to the surface of the water enables the guard to arrange the chains of the panel to a better angle for raising them.

Each regulating weir is 162 feet 4·3 inches long, and consists of a fixed part made of béton, hollowed out in the middle along the whole length—faced with masonry, and enclosed between two lines of main and sheet piles 24 feet 7 inches apart. This mass rises within 3 feet 5·25 inches of the standard level of the water, or 3 feet 11 inches above that of the summer stage. On this are placed 33 movable iron panels, 4 feet 10·5 inches broad, rising when upright 3 feet 3·3 inches above the fixed part, viz., 2 inches below the standard level. [*Plate* IV., *Fig.* 11.]

Each panel is independent of the next one, and turns round on a horizontal axis placed at about its middle point. The upper part above the axis is called the panel; the lower, which descends into a coffer or recess, the counterpanel. The panel keeps up the water. The counterpanel is capable of receiving a certain movement which it communicates to the panel. The counterpanel is enclosed in the masonry of the fixed part, the shape of the coffer being a quadrant of a cylinder. The axis of the counterpanel and coffer being coincident, the former can describe a revolution of a quarter of a circle.

The plane surfaces of the quadrant do not pass exactly through the axis; the horizontal one is slightly raised parallel to itself; the vertical one recedes a little, so that a rectangular space is left between the masonry and the counterpanel when in its two extreme positions.

The panel can either be kept in a vertical position or lowered horizontally on the down-stream side; the counterpanel takes similar but not exactly the same positions; below the axis of rotation, it is not made on the prolongation of the panel, but curves sharply backwards, and then continues parallel to the panel. This curve is given to bring the counterpanel under the horizontal opening **A**, into the lower contour of which it fits. When the panel is raised, the down-stream face of the counterpanel rests close against the vertical up-stream side of the vertical opening **B**.

The extremities of each coffer are closed by iron vertical and transverse partitions; each is pierced with two rectangular openings, so as to make the series of horizontal openings **A**, and vertical openings **B**, as it were continuous tubes. Both are of sufficient dimensions to allow of the workmen passing through to inspect the different coffers. The counterpanels divide each coffer into longitudinal compartments, of which the up-stream ones are closed by horizontal plates of iron; these plates rest in the cut stone surface of the crest of the fixed part of the dam, the two iron vertical partitions, and on a horizontal tongue of iron projecting from the axis.

In the body of the pier immediately adjacent to the up-stream and down-stream sides of the part of the regulating weir occupied by the coffers, two vertical shafts are sunk; these communicate by culverts, the one with the up-stream, the other with the down-stream, part of the river, and also with one another by means of two horizontal iron pipes placed one above the other in the masonry, and closed by valves at their extremities. These pipes are bent at right angles and pass through the mass of the masonry which separates them from the first coffer; they, however, no longer remain superposed. One placed on the up-stream side and higher, forms a junction between the horizontal opening **A** in the up-stream side of the coffers and the upper pipe in the pier; the other connects the vertical opening **B** in the down-stream side of the coffers with the lower pipe. Valves are fitted to the tubes at their entrance into the vertical shafts.

If we suppose all the valves of the tubes in the pier shut down, the panels lying flat on the weir, and, consequently, the counterpanels horizontal, and if the valve on the up-stream of the tube corresponding to the up-stream compartment of the coffers should be opened, the water from the river will immediately fill the compartment, and pressing the counterpanels with a force due to its excess of height above them, will push them forward till the checks placed in the coffers for the purpose stop

their motion exactly when the panels have arrived at the vertical position. [*Plate* IV., *Fig.* 4.]

If the valve on the up-stream side of the tube which was opened is now shut, and that on the down side hitherto remaining closed, opened, the water in the compartment will flow off into the river on the lower side; the counterpanels being freed from pressure are no longer capable of keeping the panels vertical, the latter therefore fall back on the weir. [*Plate* IV., *Figs.* 10.]

The raising and lowering of the panels depends therefore simply on the opening or shutting of two valves. As the rapidity with which these arrangements can be made depends on the time taken in filling or emtying the compartment, it is easy to understand how it could be graduated to prevent the machinery being subjected to shocks.

The panels being raised, leakage necessarily takes place round the counterpanels. If the water from this cause was allowed to accumulate in the down-stream compartment, it would soon fill it, and neutralise the pressures which keep the counterpanels in their place; the panels would then lower themselves; but this is avoided, and the water carried away as soon as it is introduced, by opening the valve of the down-stream side of the second pipe of the pier which communicates with that compartment.

To remedy the inconveniences which would arise from all the panels opening to the full at once, each has been furnished with a spur brace, whose upper end is connected with one of the arms by a hinge, whilst the lower extremities drags in a cast-iron race fixed on the crown on the fixed part of the weir. A sliding bar placed in a groove made for the purpose in the glacis, a little in rear of the position occupied by the foot of the spur brace, extends horizontally from one end to the other of the regulating weir, and traverses all the races or guides. The sliding bar is angular in form; the horizontal branch is level with the flooring; the other or vertical branch is notched at certain distances. Suppose the tubes in the pier are so acted on as to initiate the lowering of the panels. The feet of the spur braces meeting the vertical branch of the bar are checked, the panels therefore remain upright; but if the bar is moved so that one of its vertical grooves correspond with apertures in the race, the feet of the spur braces will glide along without stopping. It is clear that by spacing these grooves in a certain way, any number of panels may be lowered at will. Even this arrangement does not give that com-

plete control which is required; for the panels whose spur braces meet the grooves will be lowered entirely, and thus allow a depth of 5 feet of water to pass down. Such a mass suddenly thrown on to the apron would in all probability cause considerable and dangerous scour; it becomes, therefore, necessary to find some method of lowering a fixed number of panels only partially. This is obtained by introducing on the glacis other notched bars, similar to the one just described. A second one so arranged as to check the panels when lowered down half of their height, has been considered sufficient.

The notched bars should only be worked when the panels are kept vertical merely by the pressure of the water on the counterpanels, in order that the foot of the spur braces should not rest against the bars, and that thus the only resistance to be overcome in giving the longitudinal movement should arise from the weights of the bars themselves. As the notched bar is placed on the masonry in a part raised at least 3 feet 3·3 inches above the summer level, it can easily be cleared of all matters which impede its movement.

The spur braces and notched bars just described add considerably to the complication of the machinery, and have been omitted in the most recent works.

The system of tubes and valves, by which the raising and lowering of the panels is effected, was originally only applied to the pier, but has since been extended to the abutment or wingwall, with the following advantageous results:—

1st. The quantity of water thrown into the compartments is twice as great; and, consequently, the raising and lowering of the panels becomes more sure and rapid.

2nd. A current is engendered, to carry off all foreign substances which might have gained an entrance into the work.

This is effected as follows:—

Supposing a deposit to have formed in the up-stream compartments and in sufficient quantities to be in the way of the counterpanels,—as they rise, it will be carried, by the movement of the latter, to the lower edge of the horizontal opening A of the diaphragm; there it will remain on the flooring, as we may call it, of this long tube, temporarily formed from one end of the regulating weir to the other—the tube presents no projections on its sides or bottom. The arrangements for cleaning it are then made

from the abutment and pier, the dispositions in the two being exactly opposite. The up-stream water admitted through the abutment leaves the deposit on the first counterpanels untouched; these, as far as the middle of the weir, yield to the pressure; but there the current, unable to displace the counterpanels kept in place by the pressure from the down-stream side, entrains the whole of the deposit it meets as far as the upper pipe in the pier, and forces it through into the river on the down-stream side. Whilst this is being done on the upper side from the abutment towards the pier, the opposite action is going on from the pier towards the abutment in the down-stream compartments. By these means, half of each of the two sets of compartments are second out; the other half is operated on by reversing the working of the sluices.

3rd. It has been found that the action of the valves or sluices alone give the required power of lowering any definite number of the panels at will.

It is easy to understand that if all the panels are upright, and if we open in the pier of the down-stream and close the up-stream valve of the pipe corresponding to the up-stream side of the compartments, whilst the opposite arrangement is made in the abutment, a current will set in in the compartment, the pressure of which will be very great near the abutment, but will go on decreasing; as this stream of water approaches the pier, it has so much diminished in power as to be unable to keep the panels upright; two or three will lower. If now we close the down-stream valve in the pipe corresponding to the down-stream side of the compartment, and open the up-stream valve, a current will be produced strong in the pier and decreasing towards the abutment; consequently, a certain number of fresh panels will lower.

Between these pressures and counterpressures which act at the same time on all the panels, with a variable intensity and in opposite directions, one overpowering the other at one extremity, and *vice versâ* at the other, there will necessarily be a point where the two forces are in equlibrium. On one side, the panels being in different stages of lowering and on the other, of rising.

By judiciously moderating the opening or closing of the valves, complete control can be exercised over every panel.

A considerable simplification has been introduced in the working of the valves of the pipes. It will have been observed from the preceeding observations, that, in each of the two tubes, when the valve at one of the

extremities is closed, the other is open; there is, therefore, no difficulty in connecting the valves by a cross beam, and thus reducing the number of valves to be acted on by one half. Again, if instead of regarding the two tubes, one for lowering and the other for raising, the panels, not by themselves but together, it will be noticed that when the opening in the up-stream side of one is closed, that of the other is open, and that the same occurs on the down-stream side; so that when they are placed above one another, a single valve at each extremity will suffice; and as the movements of these two are in opposite directions, the one being lowered while the other is raised, they can also be joined by a cross beam—thus the two valves connected together and worked by one agency take the place of four.

*Working of the dam.*—Supposing the dam closed and the discharge of the river nearly that due to the summer stage; the spaces between each panel are closed in order to keep the water up to the standard level, and an overflow of 2 inches takes place over the crest. If the discharge increases, the joints are uncovered. Should the water still continue to rise, it is allowed to do so without causing any inconvenience till the depth on the crest reaches 1·5 feet, the panels being so arranged as not to open spontaneously till that head is attained. When the height still further increases, the panels of the regulating weir are partially opened; if this is not sufficient, the whole of the movable part is laid flat on the flooring. The closing of the river is gradually made by raising the panels, partially at first, and subsequently to their full height.

When the season of flood arrives, the regulating weir is completely lowered, and the frames of the navigable pass are laid flat on the flooring; then the panels being tipped by means of the sliding bar, the pass is free of all obstacles. When the depth of water in the river falls below 5 feet 3 inches, we prepare to raise the dam. To do this, the frames of the pass are first put in position, then the service bridge for supporting the crab-winch which is laid above. Each frame carries a chain hooked on to the lower segment of the panel in front of it; this chain is drawn upon by the crab, and the panel is raised; when the ascending movement is complete, viz., when the spur braces rests at its lower extremity in front of the check plate, the panel frame is left open on its axis, and the same operation is performed on all the other panels of the pass. When all are upright, the panel frames are closed either by pressing down their lower segments, or drawing on the upper segments by means of an iron hook.

If the discharge of the river is feeble, and, consequently, no fear is entertained of causing too great an afflux during the closure of the pass, the panel frames need not be left open on their axis of rotation, so that each panel when raised from the floor is dressed when its spur brace rests against the check plate.

Experience has proved that the last panels can easily be raised under a head of 3·25 inches.

When the navigable pass is closed, the upper frame is fixed on each of the frames of the service bridge, and a platform of planks laid above.

*Observations on the system.*—In using regulating weirs fitted with panels and counterpanels, the crest of the fixed portion of the work must rise considerably above the summer level. In fact, in order to facilitate the construction, maintenance and the repairs of the coffers in which the counterpanels are lodged, these coffers are generally placed above the summer level of the river; and as the counterpanel is about equal in height to the panel, the crest of the fixed part of the weir should divide the summer and normal level about equally. On the Marne, the crowns are raised about 3 feet 11 inches above the summer level. If the crown had been placed merely 1 foot 7·6 inches below the summer level, as the height of a panel must have been 4 feet 11 inches, and its counterpanel is nearly of equal length, the coffers must have been carried down 3 feet 3·4 inches below the summer level; under such circumstances, both the construction and maintenance would have been costly and difficult. It is also necessary, for the proper working of the machinery, that the fixed part of the regulating weir should cause a head of water sufficient to set in motion the movable parts. The substitution of iron for masonry does not mitigate the effects here mentioned. M. Desfontaine is, however, of opinion, that provided the masonry is water-tight, no great difficulty will be experienced in lowering the bottom of the coffers as much as 1·25 foot below the summer level. The equality in height of the panels and counterpanels subsists in most of the dams constructed on the principal under consideration, but M. Desfontaine regretted that he had not made the counterpanel 1-10th longer; and in the dam of Courcelles they were made 3 feet 9·2 inches, the panels being 3 feet 4·5 inches—the result is a much greater sensibility to movement.

The normal height of the eight dams of the Marne varies between 8 feet 1·6 inch and 6 feet 7 inches above the summer level, the mean height

above being 7 feet 3·3 inches, so that allowing for an overflow of 2 inches, the crest of the panel rises 7 feet 1·3 inches above the summer level.

If this system should be applied to dams of greater height, such as for instance, where the crest is to rise 9 feet 10 inches above the summer level, the crown of the fixed part of the regulating weir must be levelled off at a height of 4 feet 11 inches above the summer level, the coffers being described with the same radius. The difficulty, under such a head of water, of closing the panels of the navigable pass necessitates the use of the service bridge laid on iron frames, which we have described. From it, and through the action of a travelling crab-winch, all the panels of the pass, with their appendages, can be drawn up from their position on the flooring.

The iron frames being thus required, it was natural to utilise them still further as a means of constructing a supplementary dam closed by needles, as in M. Poireé's system, and as affording a channel of communication between the lock and the pier.

In a dam not self-acting, it may often happen that the water, either in consequence of a sudden flood or owing to the opening of a dam up the stream, rises higher over the crest than is desirable; this may take place at night when the watch is less strictly kept than during the day.

To prevent, under such circumstances, the panels of the navigable pass from opening, it will be better to place the axis of suspension higher than is the case where the dam is intended to act spontaneously—about the middle would perhaps be the best position.

*Dam of Joinville.*—The dam of Joinville is the last work completed on the system invented by M. Desfontaine. It was finished a few weeks after the death of that Engineer (10th of October, 1867), and exhibits the latest improvements suggested by his great experience.

*Object of the dam and general arrangement.*—This dam is intended to secure the navigation of the Marne near its site, and to raise the water for feeding the lakes of Vincennes and certain parts of Paris, without interfering with the vested rights of the mill owners, &c., below.

The navigable pass was not of much importance in this particular case, and was only made with a breadth of 39 feet 4·3 inches, its cill being fixed 1 foot 7·6 inches below the summer level.

The regulating weir is so arranged as to afford ample waterway during the great floods; it is 206 feet 7·6 inches long, surmounted with movable panels 3 feet 7·3 inches high.

The whole dam, including the two abutments and the pier which separates the regulating weir and navigable pass, is about 328 feet long.

The afflux caused by the dam is 7 feet 0 96 inches above the summer level.

The navigable pass is constructed on M. Poireé's system; the regulating weir, as stated above, on M. Desfontaine's, with these important modifications—1st, The spur braces of the panels of the regulating weir are suppressed; 2nd, Small iron frames, destined to support beams 9 feet 10 inches long, take the place of the intermediate piles which were intended to form points of support for planked cofferdams 39 feet 4·3 inches long.

*Description of the regulating weir.*—The regulating weir is comprised between two rows of main and sheet piles braced together; these are placed 26 feet 3 inches apart from centre to centre. The braces on the up-stream side are level with the fixed cill, at a depth below the normal water level of 3 feet 7·3 inches; the braces on the down-stream side are at the summer level. These frames were only driven down; the excavation to receive the béton, together with two side excavations, extending 3 feet 3·3 inches deeper, had been made by dredging.

The excavation of the central part was determined, having in view the possible filtrations and the expense.

The minimum thickness of béton was fixed at 3 feet 11 inches. This béton was poured in below the flooring, which is 1 foot 3·7 inches deep, and forming the foot of the down-stream slope of the superstructure, is level with the water on the down-stream side during its summer stage.

The béton was carried down below the bed of the river to a depth of about 1 foot 7·7 inches. No intermediate filling in of blocks of stone was permitted, from fear that the constant passage of water between the stones would modify the state of equilibrium and create dangerous empty spaces in the mass.

That such is the effect on loose stone work exposed to the constant infiltration of water has been repeatedly observed; thus in the dam on the Oise, great alterations were noticed in the body of dry stone owing to the pressure, &c., of the backed up water. In the dam of Verberie, the exterior slope sank under the weight of a conductor, who narrowly escaped breaking his leg; it appeared that a considerable scour had been caused by the wear and tear of the infiltrating water, and that some of

the stones had been carried away. In many cases, the lower stones in the exterior slopes when not packed tightly, have been seen to rise from the subpressure and fall back from their own weight; so that the stones are constantly undergoing the process of wearing away under the action of friction.

Although the dams on the Marne were always constructed on a rise in the river bed, yet the depth of béton has had sometimes to be considerably increased beyond what was first intended; this arose from the work being necessarily executed over only half the breadth of the river at the same time, so that the water heaped up on the other half scoured deeper than was expected. In the dams previously built, the mean depth of 4 feet 5 inches had not been passed, but at Joinville the mean thickness of the béton reached 5 feet 3 inches.

The length of the regulating weir being 206 feet 7·6 inches, the béton poured in filled up a rectangular space of 206′ 7 6″ × 26′ 3″. Owing to various accidents, arising from the unexpected height to which the water rose and remained, during the exceptional flood year 1866, the béton first poured in was partly disturbed and broken. It, therefore, became necessary to protect the work against another recurrence of such a mishap. This was done by establishing, outside of the frames of main and sheet piles, two great cofferdams of earth, the one on the up-stream, the other on the down-stream, side of the regulating weir. Under their protection, the masonry was laid on the béton. This mass of masonry was formed into a kind of coffer, open for a breadth of 6 feet 11·4 inches, and extending along the whole length of the regulating weir. The transverse section of the opening is nearly a quarter of a circle with a rectangle adjoining; the quarter of a circle on the up-stream, the rectangle on the down-stream, side. The top edges of the opening are faced with cut stone; that is, the up-stream side is carried up within 3 feet 7·3 inches of the normal water level, and constitutes the fixed cill of the weir; that on the down-stream side is placed 4 7 inches lower, and forms the top of the curved slope down which the overflowing sheet of water falls. When this opening in the masonry was completed, it was divided into sections 4 feet 11 inches long, by great plates or diaphragms of iron. Each diaphragm is pierced with the horizontal and vertical openings previously described, and penetrate, on the whole perimeter of the coffer, 3 inches into the masonry. In every coffer thus formed, a panel with its counterpanel was

fitted. The panel sluice (calling the panel with its counterpanel by that name) is formed of 3 strong bars, 7 feet 10·8 inches long, and two sheets of 2-inch iron; the counterpanel curves backwards 1 foot 4·5 inches, and then continues parallel to the prolongation of the panel. The movement of the counterpanel is checked—1st, By a cill of wood 6 inches square, against which the lower edge rests when the panel sluice is raised; 2ndly, By two flanges, 1 foot 1·8 inches, which support the diaphragms; and, 3rdly, A horizontal projecting piece of cast-iron under the hinge, against which the counterpanel rests at its upper edge. As the counterpanel moves in its coffer, its side edges approach within 3·3 inches ($\frac{1}{8}$-inch) of the plane surfaces of the two diaphragms and cylindrical surface of masonry. The masonry is plastered over with a coating of Portland cement.

When the counterpanel is upright, no water escapes by any of its four edges. This water tightness is further assured by four strips of india rubber fixed on the down-stream face. In every other position, a little leakage takes place by the spaces between its edges and the surface of the coffer.

Combining these details with the general descriptions given in previous paragraphs, we find the regulating weir presents the following appearance.

A row of piles braced together 3 feet 7·3 inches below the normal water level.

A platform of ashlar masonry.

An iron plate covering the up-stream compartment of each coffer.

A panel sluice, which can be lowered on a cast-iron plate, covering the compartment on the down-stream side.

A second platform of cut stone, connected by a curved sloping wall, with the braces of the second row of piles at the level of the low water on the down-stream side.

The abutment, which is 9 feet 10 inches broad by 24 feet 11 inches long, is pierced in the middle by a culvert varying in section; at the two extremities along a length of 4 feet 3 inches, the breadth is 3 feet 3·3 inches, so that it can be easily examined. The portion in the up-stream side has its floor 1 foot 3·3 inches above the summer level of the up-stream water; that in the down-stream side has its floor exactly level with the summer level. In the middle and along 9 feet 10 inches of its length, separated from the two extremities by the two vertical shafts which connect the culverts with the top, is the essential part of this aqueduct,

that which distributes the water by means of which the working of the weir is performed.

In this central part, the culvert divides into two others, into two rectangular tubes placed one above the other, and separated simply by a cast-iron plate ·787-inch thick; these tubes are each 2 feet 7·4 inches broad and 1 foot 11·6 inches high. An ordinary cast-iron valve placed at the up-stream head closes one of the orifices while opening the other. A similar valve in the down-stream side performs the same function. An equibrachial lever connects the rods of the two and communicates an inverse motion.

From these two superposed tubes, branches are made at right angles through the mass of masonry which intervenes between them and the first coffer—one branch, the higher, leads to the horizontal opening in the diaphragm (A), and the other to the vertical (B).

*Working the machinery.*—Supposing it is required to raise the panels from the horizontal position; we have only to lower the up-stream valve ; by doing so, the lower orifice is closed and the upper tube placed in communication with the river on the up-stream side; and, as by the nature of the construction, the upper tube is closed at the same time on the down-stream side, the water from above can only be directed into the up-stream compartment of the coffers; it presses on the first counterpanel and forces that panel sluice into the vertical position; it then passes on to coffer after coffer through the horizontal openings, performing the same operation until all the panel sluices are upright.

If the panels are to be lowered, the up-stream valve is raised; by this single movement, the upper, and, consequently, the whole line of the up-stream compartment of the coffers is relieved of any pressure from the up-stream side, and is free to empty itself, whilst the lower tube, and, consequently, the down-stream compartment of the coffers shut off from the entrance of water from the river below, receives in its turn the overpowering action from up-stream; the counterpanels thus taken in reverse rise towards the up-stream side, and the panels fall flat without jolts or shocks.

The power of raising and lowering the panels depends very much on the difference of level between the water on the two sides of the dam. A head in the up-stream side can be caused either permanently by the establishment of a masonry cill, on which the movable plates are placed,

or temporarily by the entire or partial closure of the navigable pass. In summer the head will be at its maximum, and the current at its maximum. As the river rises, the head will decrease, and the velocity increase till it becomes impossible to raise the panels.

Practically, there are two resistances due to friction which have to be overcome. The first is that arising from the friction of the three collars of each panel on the axes of rotation. Articulations of this description worked below torrents of waters are liable to bend and to be affected in a manner no foresight can anticipate. In the present case a consideration of the effective dimensions of the different pieces will go far to remove any fear as regards this view An iron cylinder 2 inches thick and only 4 feet 10·5 inches long, and clasped by six collars cast in the surrounding tube, does not seem likely to bend out of the line of the axis of these collars.

The other passive resistance results from the counterpanels not being able to move without driving back the water from those coffers which are filled, and expelling it through the discharge channels in the pier and abutment. The friction of the water against the surfaces of the masonry, &c., the contraction of the section, and the alterations in direction give rise to resistance which increases in proportion to the velocity with which the expulsion is attended; these retarding effects are so far useful that they prevent the panels from falling suddenly.

In practice, one imperfection must be noticed; as the resistance in-a greater effort is required to set the counterpanels in motion; the motion also when transmitted is slow; the water arriving simultaneously in contact with a large number of counterpanels, leaks out in considerable volumes by the edges, and is not sufficiently powerful to act on all the panel sluices.

Such are the different elements of the problem.

At Joinville when the water on the down-stream side is at the summer level, a head of 4 inches to 6 inches is sufficient to raise the panels. If the navigable pass is closed completely, the raising takes about two minutes —one minute is sufficient for the lowering. On the 5th March, 1866, the water standing at 7 feet on the up-stream side, and 4 feet 7 inches below, the raising took twelve minutes and the lowering five; on another occasion, the water standing 6 feet 6·7 inches up-stream and 4 feet 11 inches below, half an hour was spent in raising the panel sluices. This latter is nearly

the limit of the action of the dam—it would have been easy to extend it if desirable, but no object was to be gained by doing so.

We have noticed previously a curious and important property of this kind of dam, that it is within the power of the sluice-keeper to lower any number of the panel sluices he wishes, down to only one if such should be necessary; this is effected without the use of the spur braces, which, together with the other portions of their machinery, are omitted in the dam we are considering, so that one great complication is avoided. With a little experience, the sluice-keeper can judge the amount of water to be admitted in order to lower or raise a certain number of the panels, and adjusts accordingly the degree of opening to be given to the valves.

The entrance of foreign matters is guarded against by gratings placed on the up-stream side of the culverts in the abutment and pier, and by sluices established behind them. The sluicing out of all matters which have found admittance is easily effected, as we have described in a former paragraph.

The cavity of the regulating weir is protected longitudinally by the walls which encase it, as high as 3 feet 0·9 inches above the summer level on the down-stream side, and 3 feet 5·7 inches on the up-stream side. In order to isolate any recess completely, and to facilitate its being laid dry, when the water does not rise over the down-stream crest of the weir, viz., when the water does not stand over 3 feet 0·9 inches above the summer level, M. Desfontaine in former dams, merely established a small cofferdam on the pier and another on the abutment, grooves being made on the line of the culvert for the purpose; but at Joinville, as the standard level of the water could not be lowered, he caused a number of triangular frames 3 feet 7·3 inches high to be arranged on the up-stream crest of the regulating weir (enlarged 1 foot 3·7 inches for the purpose) to act as supports for a framing of planks. As the planks are only 8 feet 6·3 inches broad, and 4 inches thick, they are easily carried, more especially in the quiet which reigns on the up-stream side of the panels, and where the boat can work without danger. These planks are provided with hooks, which keep them firm on the uprights of the frames; tarpaulins weighted with pieces of iron are fastened on the up-stream side. The quantity of water passing through such a protecting curtain is exceedingly small.

A little traversing crane has been placed on the fixed part of the weir in such a way as to travel from one extremity to the other, which it does

with great ease. In less than a day, the plates covering the coffers can be unscrewed and removed, and the 82 panel sluices with their hinges raised, so that everything may be inspected, after which the whole is replaced as it was at first. The pump is only employed when it is necessary to lay the coffers dry. The scrapers passed through the coffers at the end of the first winter did not meet a particle of mud or sand. The gauge of the diaphragms or partition plates of the coffers, was carefully kept during the fixing of the movable panels by means of four iron rods furnished with screws at their extremities: they now remain buried in the masonry.

The fixing of the ironwork and movable machinery took six weeks.

*Price of the work, &c.*—The movable machinery of the regulating weir and its adjuncts cost, £1993·79, as the following table shows:—

| Name of the piece, &c. | Per unit. | | Number of pieces in the dam. | For the entire weight. | Work value. |
|---|---|---|---|---|---|
| | Weight. | Value. | | | |
| | lbs. | £ | | lbs. | £ |
| Diaphragms or partition plates (cast-iron), each, .. .. .. | 1,437·39 | 13·12 | 43 | 61,807·9 | 564·43 |
| Gauge rods, per coffer, .. .. | 56·82 | 0·90 | 42 | 2,387·0 | 37·88 |
| Wrought-iron covering plates on the up-stream side, .. .. .. | 246·29 | 3·96 | 42 | 10,344·4 | 166·43 |
| Cast-iron covering plates on the down-stream side, .. .. | 463·51 | 4·64 | 42 | 19,467·8 | 195·16 |
| Hinges of the sluice panels with their axles, .. .. .. | 481·97 | 6·93 | 42 | 22,243·3 | 291·28 |
| Wrought-iron sheets and arms of the panels, .. .. .. .. | 793·73 | 12·38 | 42 | 33,336·6 | 537·50 |
| | | | feet. | | |
| Lower checks of the counterpanels per foot run, .. .. .. | .. | 0·173 | 2067·6 | .. | 35·79 |
| Grooves for the iron work, per foot run, .. .. .. .. .. | .. | 0·285 | 2067·6 | .. | 59·20 |
| Fixings, .. .. .. .. | .. | 0·146 | 2067·6 | .. | 30·32 |
| | | | s. ft. | | |
| Plaster in cement, per square foot, | .. | 0·037 | 1356·26 | .. | 50·40 |
| Various expenses, .. .. | .. | .. | .. | .. | 25·36 |
| | | | | | 1993·7 |

The price of the machinery is, therefore, £96·4 per running foot.

The pier and abutment cost as follows:—

| | £ |
|---|---|
| Valves, with their gear, including the plate separating the two tubes, .. .. .. .. .. .. .. | 51·08 |
| Up-stream grating, .. .. .. .. .. .. | 12·84 |
| Sluices for preventing the entrance of foreign matters, .. | 10·00 |
| Planks for cofferdams, .. .. .. .. .. | 6·20 |

| | £ |
|---|---|
| Ladders, .. .. .. .. .. .. .. | 3·56 |
| Grooves, .. .. .. .. .. .. .. | 5·40 |
| Fixing, .. .. .. .. .. .. .. .. | 1·60 |
| Pumping, &c., .. .. .. .. .. .. .. | 1·32 |
| Total, .. | 92·00 |

The small travelling crane cost £38·02.

The cofferdam of frames and planks, which is placed on the crest of the weir, cost £1·219 (£1 4*s.* 4·56*d.*) per running foot.

The eight dams constructed previous to the Joinville cost about £28·65 per running foot (taking merely the regulating weir); this is divided into £19 for the mixed part, and £9·65 for the movable portion; the latter rate is almost exactly the same as in the Joinville dam.

*Metal coffers.*—The coffers were at first (1846) lined with iron; such exist at the present day, in the dams of Damery (1858) and Courcelles (1862), and these remain in perfect order; but two serious objections have occurred to counteract their advantages.

1st. The possible oxidation of the iron, not in the panels, which can be protected; but at those points which are fixed and hidden from view.

2nd. The difficulty of fixing the flexible iron on the cylindrical surface and the vertical sides, so as to fit closely against the edges of the counterpanel.

By substituting masonry covered with plaster, the first has been avoided, and the second much lessened, for the cylindrical surface is smoothed now with mathematical precision by means of a knife, which, moving with the counterpanel, operates on the fresh plaster.

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## Comparison of the Systems.

*M. Poirée's for navigable passes; M. Chanoine's do.; M. Chanoine's for regulating weirs; M. Desfontaine's do.*

*M. Poirée's.*—The two great inconveniences of this description of dam are the difficulty of making it water-tight under a considerable head, and the impossibility of increasing the sectional dimensions of the needles while adding to their height; and, consequently, to the pressures they have to support.

Several other disadvantages have been urged against the system.

1st. The placing in position and removing needles when the frames are above 8 feet in height is a difficult and dangerous operation. If the needle does not meet the cill of the flooring against which it ought to abut, the guard may be carried off with it. On the Lower Seine, where the navigation is continuous and night work unnecessary, accidents from this cause are rare; the weight of the needles, even when the standard level is 10 feet and the frames 11 feet high, does not exceed 33 lbs., so that one man can carry two at a time, and as the projecting cill of the flooring, against which the lower end of the needles rest, is 6 inches, they generally catch properly; but in rivers, such as the Yonne, whose regime is torrential, and where the navigation is intermittent, accidents are more frequent; thus in 1859, at the dam of Epineau on the Yonne, a guard was drowned; on the Belgian Meuse, the guards often fall into the water; for instance, in 1866, two were drowned at the dam of Haignaux.

The adoption of machinery is supplanting manual labor in the operation of raising the needles; though even under a head of 10 feet, a skilful man is said to be able to perform that work with ease; thus, at the dam of Suresnel, on the Seine below Paris, which was completed in June 1867, M. Savarin has been obliged to use a crab placed in a boat to raise the needles when the head attains a height of 6·56 feet, and he states, that on the Lower Seine, the sluice-keepers never raised or put in the free pass, the 13 feet needles, unless the head of water was below 5·25 feet.

2nd. The guard is exposed to great danger from having to traverse a narrow foot bridge to attend to the works; and this has to be done at night as well as by day.

This objection has been met in the later dams by increasing the breadth of the service bridge from 2 to 3 feet.

The point, as to whether a foot bridge or boat forms the best platform from which to work the movable machinery, is still disputed. On the Lower Seine, men are seldom out at night work, except where the dams are within tidal influence, or at a time when a dam higher up the river is being opened; but unnecessary watching is easily avoided in the latter case, by keeping the guard of the intermediate dam acquainted with the intentions of the guards of the upper and lower dams.

3rd. Boats near the lock may, during the rising of the needles, be entrained by the current engendered, and carried down on to the frames.

This danger is reduced by placing the dam further away from the head

lock gate: in practice, it is never less than 230 feet below, and generally about double that distance. The needles can also be removed from any bay, sometimes at one point, sometimes at another, as most convenient.

4th. The raising of the needles leads to a scour on the down-stream side of the navigable pass.

The scour is never concentrated on one point, but equally along the whole length of at least a bay, and the flow is always the entire stratum above the flooring, and of a larger passing over the top. Besides, it is during the heavy floods, when the dams are flat on the bed of the river, that scour takes place below them.

On the Yonne, hardly any scour appears to have taken place. Thus M. Cambuzat states, that the dam of Chainette, finished in 1860, has experienced no damage during 6 years—in the case of the dams of Epineau and Joigny, finished in 1840, the scour on the down-stream side has been inconsiderable—but at the dam of Joinville (1867), very considerable scour speedily occurred after the completion of the work.

5th. The frames, when laid down, should be flat on the flooring; no part should project above; this, however, is said to be difficult to ascertain where the depth of water exceeds 6·5 feet. Even when the frames are in their proper position, they still remain exposed to damage from boats or drifting logs.

Formerly chains used to be attached to the frames; these, however, proving a great hindrance to their careful laying have been discontinued. The projection of the cill above the flooring is now made 1·3 inches or 1·4 inches, which seems sufficient to stop a boat drifting down on the cill, and as the flagging of the down-stream side of the floor as well as the enclosing frames of wood are level with the cill, and further, as a floating body would plunge downwards, it is not likely that the frames which are placed below the level of the cill, and only occupy a space 9 feet 10 inches in breadth, would afford a lodging point for boats, &c. It is also stated that the verification of the position of the frames when lying on the flooring presents no difficulty, however strong the current may be.

6th. Deleterious matters accumulate on the up-stream side. The question of insalubrity is common to all dams; but the withdrawal of two or three needles being sufficient to allow the passage through of the carcase of a sheep or dog, constitutes a remedy which can be easily and quickly applied.

*M. Chanoine's.*—A great disadvantage of the system is the difficulty of rendering the dam water-tight. Every two consecutive panel frames have a space left between of 4 inches; this is necessary from their being of wood; panel frames of iron would require a smaller free space, but their weight, when their height exceeded 10 feet, would necessitate a diminution in their breadth and increase the number of intervals.

To cover these spaces completely, pieces of wood 6 inches square and 11·5 feet high, are required (when the head of water stands at 10 feet); the pressure against such a strip of wood is 2023 lbs., so that machinery, either worked from a boat or a foot bridge above, becomes necessary under certain circumstances. It may be dangerous to bring the boat close to the panels, and a foot bridge is not an integral part of the system, though it would be a mostv aluable adjunct; the piece of wood, if allowed to remain, will float off when the panel frames open, but it is clear that they thus impart a rigidity to the whole movable frame of the dam, and by compelling all the panel frames to open simultaneously, interfere with the individual action so useful in regulating the flow. Further, when the planks are removed, it will be necessary to replace them,—a delicate operation, and one which must be repeatedly performed.

We have noticed, under the proper head, that the self-acting panel frames of the regulating weir can fall into such a position as to lose their sensibility to return to the perpendicular.

If the full development is to be given to their use, and the length of the regulating weir consequently brought within narrow limits, they must be looked on as semi-self-acting, viz., opening spontaneously, but not always recovering themselves without the assistance of the sluice-keepers.

To obviate these disadvantages, and bring the work under control, it has been proposed to add to the regulating weirs, already constructed on this system, a series of frames about 8 feet high, placed 9 feet apart, on which a service bridge of planks could be raised, and free access afforded along the whole work; thus the opening of the panel frames could be modified at will; those, below which any tendency to scour showed itself, could be raised immediately; the planks covering the joints could be removed or replaced, and the whole of the regulating weir could be opened previous to the opening of the navigable pass, and the resulting shock of water thus deadened. Recently, (21st October, 1868,) the necessity of these service bridges has been impressed on the Engineers in charge of the

navigation works on the Yonne, for on that date a flood descended the Armancon, an affluent of the Yonne, and opened the panel frames of the regulating weirs of the whole of the dams between Laroche and Paris. These service bridges are adopted on the Marne, and are calculated to cost when applied to the Seine, about £4 16*s.* the running foot, which would bring the total expense of the regulating weirs up to £22 the foot run.

The great advantage of the system consists in the facility it affords in conducting the navigation by means of flushes.

The self-acting regulating weir is a great advance on the fixed weir formerly joined with M. Poireé's system of navigable passes. As, however, M. Poireé's passes can be attached to regulating weirs, constructed either on M. Chanoine's or M. Desfontaine's plan, it will be sufficient to mention the advantages obtained by adopting the latter.

The regulating weir draws off at all events for some part of the time the currents from the navigable pass, and reduces the danger caused by the shock of floating bodies. It mitigates the scour when the navigation is intermittent, which would otherwise take place in the navigable pass, for as we have seen, it can be opened first and thus be enabled to pour down a sufficient quantity of water to form a cushion as it were, to break the force of the water issuing from the latter, the most delicate portion of the work; the danger of scour is thus confined to one particular spot, and that the least easily injured. The question as to whether the machinery is more easily deranged than is the case in M. Poireé's system seems to be doubtful. The panel frames when laid flat on the crest of the dam certainly cover their machinery, and being pressed by the whole force of the current are not likely to project above their proper place, but they are more exposed than M. Poireé's frames, as the latter are sunk about a foot below the surface, and if a boat should drag on a panel it would draw it up together with its appendages.

M. Malézieux notices an instance of this which occurred at the dam of Dammery on the Yonne. M. Cambuzat has also recorded that numerous accidents have happened to the dams under his charge in the Yonne. "The repeated shocks of the jointed arms on the flooring, the presence of a stone or a piece of wood injure the sliding bars and jointed arms, and sometimes prevent the lowering of the panel frames." M. Malézieux corroborates this statement, he writes: "The nine new dams finished this year are now at work, and certain fears previously entertained have been confirmed; some of the sliding bars have clogged in their

guides and remain immovable, the raising of the panels at all times a laborious work, becomes particularly so when the last are being acted on, some have fallen after being raised, owing to the spur braces spontaneously slipping away from the check plate. Sometimes, in consequence of the water having accidentally fallen on the flooring on the down-stream side, a sufficient depth has not remained to soften the shocks of the falling panel frames, which, in consequence are broken." M. Lagréné, on the other side, mentions that the barrage of Melun with a navigable pass closed by 50 panels, had been opened 50 times in 1865, without a single accident having happened.

A comparison of the time employed in working dams constructed on M. Poireé's and M. Chanoine's system is given below:—

| NAME OF THE OPERATION. | TIME. | | |
|---|---|---|---|
| Dam of Courbeton. | Employed in the operation. | Mean at an ordinary flushing. | Per running foot. |
| *Closing.* | h. m. | h. m. | |
| Raising 35 frames of the navigable pass, and carriage of the planks of the service bridge,.. .. .. .. .. | 1·45 | 1·30 | |
| Loading and carrying by boat, 515 needles, | 1·15 | 0·45 | |
| Fixing the needles in the dam, .. .. | 1·15 | 1·15 | |
| Passing the ropes through the head of the needles, .. .. .. .. .. | 0·40 | 0·40 | |
| Total time employed in closing the dam, | 4·55 | 4·10 | |
| *Opening.* | | | |
| Time employed in lowering the frames, .. | 0·30 | 0·30 | |
| Time employed in taking the needles out of the water and carrying them to the wing-wall, .. .. .. .. .. | 3·0 | 3·0 | |
| Time employed in placing them in store, .. | 2·0 | .. | |
| Time employed in removing the ropes from the water and placing them in store, ... | 0·20 | 0·20 | |
| | 5·50 | 3·50 | |

Under similar circumstances the navigable pass of the dam of Conflans, constructed on M. Chanoine's system, was opened 10 times more rapidly, and 60 times as quickly if all the operations are taken into consideration.

The closure was also executed three times as rapidly, and the Engineer in charge states, with less difficulty and danger.

*M. Desfontaine's.*—This system, if it can be called so, has been applied up to the present time merely to crown regulating weirs, and it appears probable that it must be confined to such parts of river dams. In that point of view it carries away the palm from M. Chanoine's system. The motion of raising the panels is simple, whilst that of the panels of M. Chanoine's pattern is double and complex. The Desfontaine's panel rises upright without the assistance of any detached machinery, the force utilised is not that of a man transmitted by mechanical means, but the very power it is required to overcome; the method of obtaining this result is very simple, the agency consists only of a few valves connected by a beam acting under a single and easy impelling power, and of panels of a single piece turning round on an horizontal axis without any complication of counterpoises, traction chains, spur braces, or sliding bars.

One objection of considerable force can be urged against the system, viz., the fixed part is much higher than in M. Chanoine's dams, and therefore presents a greater obstacle to the flow of the river. It is, however, attended with the following advantages—1st, A fixed work in masonry is more secure than a movable screen; 2nd, A movable work placed higher above the bed is easier to inspect, repair, &c., and is less likely to be clogged with sand and other foreign matters; 3rd, A certain height is required in order to produce the head necessary to initiate the movement of the machinery.

Further, the establishment of a fixed cill in the bed of a river does not reduce the discharge in the same proportion as the section, for the cill only stops the water moving with a velocity relatively slight, and a very moderate rise in the water on the up-stream side is often sufficient to produce an acceleration which makes up for the diminution in section.

The difficulty of working the panels, should any accident happen to the fixed part, is greater than in the other systems, any sinking in the masonry would injure the coffers, and render it impossible to work the counterpanels. At the same time damage is less to be expected owing to the remarkably small amount of leakage which takes place between the panels, so that whilst they are upright the current above can only acquire a very slight velocity. The panels are not self-acting so that the supervision must be more constant than where they open and shut spontaneously, and consequently the guard must be on the pier night and day, but the duty is

rendered easier as all communications take place on the foot bridge. On a non-torrential river, M. Desfontaine preferred to leave some responsibility to the guards, one of whom could without leaving the firm ground by merely giving a few turns to a winch, lower or raise the whole movable screen. Repairs can be easily carried out, the panels, counterpanels, and coffers are all above the summer level. The cavity or series of coffers is protected longitudinally by the walls which encase it for a height of 3 feet above the summer level, the coffers are closed above by metal plates, which have only to be raised when the interior is to be examined.

The cost of a Desfontaine weir is considerably more than that of one constructed according to M. Chanoine's system, as the following table shows:—

| Name of the work. | Length measured parallel to the axis of the river. | | Remarks. |
|---|---|---|---|
| | For a dam in the Upper Seine. | For a dam in the Marne. | |
| | *Chanoine's system.* | *Desfontaine's system.* | Upper Seine dam. |
| | | | £ |
| | feet. | feet. | Fixed part, ... = 12·64 |
| | | | Movable, ... = 4·67 |
| Flooring of the navigable pass, ... ... ... | 19·68 | 41·65 | Total, ... 17·31 |
| Pier (crown), .. ... | 19·68 | 41·00 | Add for frames, = 4·87 |
| Flooring of the regulating weir, ... ... ... | 14·038 | 24·60 | Grand Total, 22·18 |
| Wing wall (crown), ... | 13·12 | 41·00 | |
| | | | Marne dam. |
| Or an increase of £6·47 per running foot. | | | Fixed part, ... = 19·00 |
| | | | Movable part, = 9·65 |
| | | | Total, ... 28·65 |

In conclusion we annex the opinions of the different French Engineers who have written on the subject.

*M. Saint Yves.*—M. Poircé's navigable pass offers the maximum of simplicity in construction, and is the best for adoption on rivers whose regimen is regular, and where the navigation is continuous.

M. Chanoine's system is more suitable when the navigation is conducted by flushes, where the whole of the ponded up water is to be suddenly discharged to increase the depth of the channel below.

M. Desfontaine's regulating weir is superior to any other, provided self-action is not necessary.

*M. Cambuzat.*—M. Poireé's navigable pass on a torrential river is the best where the navigation is intermittent.

M. Chanoine's system is preferable in a torrential river with continuous navigation.

*M. Malézieux.*—M. Poireé's navigable pass is simple, and suitable for rivers not subject to torrential floods, and where the depth of water to be held up is not too great. M. Chanoine's system is infeiior in non-torrential rivers.

M. Desfontaine's regulating weir is far superior to the other descriptions.

*M. Lagréné.*—M. Poireé's navigable pass is inferior to M. Chanoine's in many respects.

M. Desfontaine's regulating weir has many advantages over M. Chanoine's, but has not yet been sufficiently tested to enable a decisive opinion to be given on the subject.

On the Meuse, all the dams have navigable passes on M. Poireé's system with fixed regulating weirs: the navigable passes are divided into two parts as shown in the accompanying sketch.

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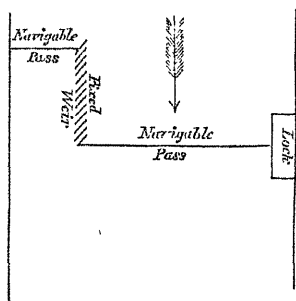
Authorities from which the above account is compiled.—

| Annales des Ponts et Chaussees. | | | | | No. of page. |
|---|---|---|---|---|---|
| 1866 Paper No. | 121 | by M. Lagréné, | ... pages | 172 to 210 | 39 |
| 1867 ,, | 146 | ,, M. Cambuzat, | ... ,, | 135 ,, 138 | 4 |
| 1868 ,, | 181 | ,, M. Saint Yves, | ... ,, | 282 ,, 306 | 25 |
| 1868 ,, | 187 | ,, M. Lagréné, | ... ,, | 50 ,, 57 | 8 |
| 1868 ,, | 200 | ,, M. Chanoine and Lagréné, | ,, | 366 ,, 469 | 104 |
| 1868 ,, | 202 | ,, M. Malézieux, | ... ,, | 482 ,, 512 | 31 |
| Memoire Lur Ses Barrages à hausses Mobiles, by M. M. Chanoine and De Lagréné, | | | ,, | 1 ,, 179 | 179 |
| | | | | Total, ... | 390 |

J. M. H.

# No. IIa.

## MANUFACTURE OF CONCRETE BLOCKS AT KURRACHEE.

*Report on Experiments lately made at Kurrachee for the Harbor Works.* By Captain Merewether, R.E., *Exec. Engineer.*

In the estimate for the breakwater submitted by me in 1864, while acting as Superintendent Kurrachee Harbor Works, provision was made for the use of concrete blocks in the hearting from 16 feet below low water ordinary spring tides to 2 feet over that level.

On the 3rd February, 1866, Government sanctioned a series of experiments being made, in order to ascertain the cost of concrete blocks of different sizes, of various materials and proportions, as to which positions in the work they might safely occupy, &c. Accordingly the experiments, of which an account is given in Part I. of this Report, were taken in hand.

In 1866, the Government, sanctioned my examining and reporting on the different localities where suitable stone might be procured for the more exposed portions of the Manora Breakwater.

It appeared from this examination (*see* No. CCXLIII. of these Papers), that stone of sufficiently good quality and of the size required, that is in blocks weighing not less than 10 tons each, could only be obtained at enormous cost, and consequently the question of the use of artificial blocks became more than ever important. Further experiments were therefore taken in hand in August 1866; of these some account is given in Part II. of this Report.

I have thought it advisable to keep the two sets of experiments separate, as Part I. contains information only as to the use of large concrete blocks for sub-marine works, whereas Part II. relates to the comparative value of Portland cement for works generally, and thus may prove of interest to some whose duties may not cause them to require the information contained in Part I., and who may therefore feel little interest in the subject of which it treats.

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## Part I.

Nine blocks, each measuring 6 × 3 × 3 feet; and, consequently, containing two cubic yards, were made. They weighed about $3\frac{3}{8}$ tons each.

They were composed of shingle and small pieces of conglomerate obtained from the quarry at Manora, of sand of toleiably good quality brought from the bed of the river Lyaree, and of different proportions of Portland cement and of the artificial hydraulic lime prepared on the Harbor Works,* sea water being used for mixing the mortar.

Of the seven blocks in which cement was used, five (*i. e.*, Nos. 1, 2, 5, 6 and 7) contained each 8 cubic feet of it, the other two (*i. e.*, 8 and 9) 12 cubic feet.

One hydraulic lime block (No. 3) contained 8 cubic feet, the other (No. 4) 16 cubic feet.

These blocks were made between the 10th May and the 5th June 1866.

Nos. 1, 5, 6, 7 and 9 were submerged on the 17th July, the others on 28th July, 1866.

They were placed by means of a crane in the sea at the most eastern angle of Manora Point, in a very exposed position.

It was intended to place them as much as possible at about mean sea-level but, as it was during the S. W. monsoon, it was impossible to form at any level anything approaching to an even surface for them to lie upon, so they were lowered on to the rough boulders of conglomerate at the foot of the cliff, and each had to find its own bed. This was of course a most severe test for them. In some cases several days elapsed before a permanent position was attained. In the meantime the position of the block was altered by almost every wave.

In February 1867, the blocks were raised and examined.

* *See* Paper by Mr. Price, published in the May No. 1867, of the Roorkee Engineering Papers.

The result of this examination was very satisfactory. Nearly all of the blocks had been lowered by means of sling chains, and consequently the arrises of some of them had suffered from the pressure of the chain. Otherwise, however, Nos. 2, 5, 7, 8 and 9 had lost none of their original quantity; 8 and 9, containing 50 per cent. more cement, appeared to be better than any of the others.

No. 1 block had not been made in quite the same manner as the rest. The materials were mixed as stiff as possible and were not rammed. The wooden moulds which had been placed in it in order to form lewis holes could not easily be drawn out. They were left in and the block lowered by means of sling chains. After the monsoon, it was found that it had broken in through one of the lewis moulds, and that the larger portion had also been cracked through the other lewis mould. There can, therefore, I think, be no doubt that the fracture was caused by the expansion of the wood (kutcha teak), of which the moulds were made. Having been broken in two, the block of course became much more liable to injury than it would otherwise have been, and it lost about 3 cubic feet of its original quantity.

No. 6 block lost more than any other, 9 cubic feet, or one-sixth part of its bulk. This could at the time only be accounted for by the supposition that the cement of which it was composed was of inferior quality. This appears to have been the case. Small specimens of the cement of which each block was made, were at the same time prepared for trial in the manner explained in Part II. (*See* Tables Nos. X., XI. and XII.—Part II.)—one of each was mixed with fresh and one with salt water.

These were tried after being kept 25 months in the air. The results as far as the tensile strength of the cement used for No. 6 block was concerned were as follows:—

The specimen mixed with fresh water broke at 565 lbs., whereas the average of all the cement used for the experimental blocks was $692\frac{1}{2}$ lbs.

The specimen mixed with salt water broke at 390 lbs., whereas the average of all the other casks used was 620 lbs.

In hardness also it showed a deficiency, though slight, the penetration of the specimens mixed with fresh and salt water being $\frac{198''}{4,320}$ and $\frac{114''}{2,880}$, the averages being $\frac{181''}{4,320}$ and $\frac{113''}{2,880}$, respectively.

Its power of resistance to crushing was not tried.

No. 3 block, containing 8 cubic feet of hydraulic lime, lost about one-eighth of its original quantity, or $6\frac{3}{4}$ cubic feet. The lime, when the block was made was considered not to be a fair specimen of that which had usually been made on the Kurrachee Harbor Works.*

No. 4 block, which contained twice as much lime as No. 3, though from the same burning, only lost about 1 cubic foot, or $\frac{1}{54}$ part of its bulk.

Altogether, therefore, it seems that the cement blocks, omitting Nos. 1 and 6 as not having had a fair chance, in consequence of No. 1 having been broken by the expansion of lewis moulds, and of No. 6 having been made of inferior cement, resisted the violence of the S. W. monsoon of 1866 very well. So far it would seem as if the superiority of Nos. 8 and 9 (containing 50 per cent. more cement) had not been proved to be sufficient to compensate for their extra cost.†

The lime used for Nos. 3 and 4 was perhaps not of first-rate quality, but it appears to have been good enough in the case of No 4, in which double the quantity was used, to enable the block to pass through the trial with very slight loss. The worse result in the case of No. 3, then, would seem to have been mainly in consequence of its small proportion of lime.

Before the S. W. monsoon of 1867 the blocks were again exposed. This time they were built up in three courses at about half tide level on a large bed of conglomerate, tolerably smooth but considerably inclined. This was in the line of the proposed breakwater, close under the cliff, if possible a more exposed position than that taken up in 1866.‡ On the 2nd June, the blocks, weighing about 29 tons, were turned over by the sea and were scattered in every direction, some being carried 13 and 14 feet. None, however, were broken by the fall.

They were taken out of the sea in February 1868, and examined, with results as below :—

Of the cement blocks, No. 6 had suffered much; it had lost fully $\frac{1}{3}$, or 18 cubic feet, of its original quantity.

No. 9 (containing the larger quantity of cement) had lost about $\frac{1}{4}$, or

* It was thought to have been kept too long in store. This does not, however, apply to the lime used in the experiments described in Part II., which was made fresh.

† $33\frac{1}{3}$ per cent., as shown in Statement A. attached.

‡ Aggregate weight. The blocks were not in any way tied or cemented together, neither was it possible in that position to bed them evenly or closely.

$13\frac{1}{2}$ cubic feet, of its original quantity. This block had been during the whole monsoon at about mean sea level.

The others appear to have been lower, and this probably is the cause of No. 9 appearing to less advantage.*

The two pieces of No. 1 suffered but little.

No. 7 lost perhaps 1 cubic foot, or $\frac{1}{54}$ of its original quantity. No. 8 (containing, like No. 9, 50 per cent. more cement) did not suffer much. Some of the angles were rounded off, two of them to a radius of about 6 inches. This block seems to have been in a less exposed position than No. 9. No. 2 appears to have stood very well, three of its sides were almost perfect, the fourth slightly injured. Four of the angles were tolerably sharp, the others slightly rounded. This block appears to have stood quite as well as 8 and 9 (containing 50 per cent. more cement), although it was probably in nearly as bad a position as No. 9, and in a much worse place than that occupied by No. 8.

No. 5 also appears to have stood very well. Two angles were tolerably sharp, two were rounded off to a radius of about 4 inches, and the others were slightly rounded. Otherwise the block was perfect.

Nos. 3 and 4 (hydraulic lime) were found to be in several pieces, the largest of which contained about 30 cubic feet. The whole quantity probably amounted to about 66 cubic feet, or $1\frac{2}{9}$ block. It was impossible to determine the block to which each piece belonged, the numbers having been worn away.

Generally, therefore, it would seem that during the S. W. monsoon of 1867, the cement blocks, except No. 6, which appears (as explained in page 81) to have contained inferior cement, and No. 9, which seems to have been more exposed to the full violence of the sea than the others, stood very well. The superiority of those containing 50 per cent. more cement does not appear to have been established.

Both of the hydraulic lime blocks must be considered as failures.

The whole of the blocks were again immersed before the S. W. monsoon of 1868. This time they were built up roughly amongst large boulders of conglomerate, in very much the same position as in 1867. They were during the monsoon moved by the waves, in some cases 10 and 12 feet from their original positions.

* There is some reason also to suspect that the cement used in No. 9 was not equal to the average.

Early in December they were examined, without being raised, with the following results :—

No. 1 seems to have suffered in 1868 very much, only about $\frac{1}{2}$, or 27 cubic feet, remaining. The two pieces, into which it was broken in 1866, were much rounded, though very hard.

No. 2 had suffered little; four of its angles were tolerably sharp, two others rounded off to a radius of from 3 inches to 4 inches, the others could not be seen. The only three arrises which were visible were good and in some places quite sharp, though this block had been slung several times.

No. 5 also seemed in a very good state. Five angles were rounded off very slightly, *i. e.*, to a radius of not more than two inches, the others to a radius of from 4 to 6 inches. The arrises slightly rounded off throughout, but only to about $1\frac{1}{2}$ or 2 inches. The faces which were visible were very good and smooth.

No. 6 was found to be an irregularly shaped mass; quite one-half, or 27 cubic feet, had been worn away.

No. 7. This Block appears to have fallen on one end in such a manner that it could be easily moved by the waves, working on that end. Consequently, the lower portion (about one-fourth) had suffered much. The remainder seemed to have stood well, arrises and angles being rounded off to radii of $1\frac{1}{2}$ or 2 inches, and from 3 to 6 inches, respectively.

No. 8 was found between Nos. 2 and 5; at one angle it had lost a piece of nearly triangular section, amounting to about $\frac{1}{6}$ cubic foot. This appeared to have been the result of friction against No. 5, though that block, containing only $\frac{2}{3}$ as much cement, had not similarly suffered at all. Otherwise No. 8 was good. All the arrises were slightly rounded, and the angles, except one which was tolerably sharp, to radii varying from 2 to 5 inches. The faces were very good.

No. 9 had lost nearly $\frac{1}{2}$, or 27 cubic feet. It had a small smooth place remaining on one face; otherwise, it must have been described as an irregularly shaped mass.

Of the hydraulic lime blocks, Nos. 3 and 4, two pieces, appearing merely as shapeless masses, were found. One was considerably larger than the other, and was probably a part of No. 4. Except No. 2, these blocks had more time than any others to harden before being exposed to the S. W. monsoon sea.

It seems, therefore, that of the five blocks containing each 8 cubic feet

of Portland cement, *i. e.*, Nos. 1, 2, 5, 6 and 7, two (Nos. 1 and 6) cannot be said to have had a fair trial (for reasons given above) and that the others (Nos. 2, 5 and 7) stood the violence of three South-West monsoons without sustaining any important injury.

Of those blocks which contained 12 cubic feet of cement each (Nos. 8 and 9) so favorable an account cannot be given. One (No. 9)* lost nearly half its bulk and almost all shape, the other (No. 8) was inferior at any rate to No. 2. It would seem therefore that little, if any, advantage is to be gained by using the greater proportion of cement contained in blocks 8 and 9. The hydraulic lime blocks (3 and 4) must both be considered failures, though it would seem that the extra amount of lime used in No. 4 had a good effect, that block having stood the first monsoon very much better than No. 3.

It must be remembered that the materials used for these experimental blocks were those which were most readily obtained when sanction was received for the trial, there being little time to spare before the S. W. monsoon of 1866. The Portland cement, a material which requires to be selected with care, even in England, was purchased without previous trial from a merchant in Kurrachee. If used for the Manora breakwater, supplies of this cement will of course be obtained specially from England, and will be subjected to a high test before being used.

The sand used was from the bed of the Lyaree river, of tolerably good quality, but not to be compared to that from Mandavee, which there is reason to believe will be procurable for the breakwater at a less cost than that from the Lyaree.

In the quality of the cement and sand used, therefore, an improvement may be expected in the event of concrete blocks being used for the breakwater.

There are several other reasons why the blocks thus used may be expected to stand, when in the work, very much better than those experimented upon.

(1). In the case of the experimental blocks, there being no railway or other means by which to convey them, if made at a distance, to the place where they were to be exposed, it was necessary to make them as near as

* This block was however exposed 43 days only after being made; this was, by 12 days, less time than elapsed in the case of any other.—*See* foot note—page 85.

† With reference to quality of cement used in No. 9. *See* Note in page 82.

possible to that point, or close under the lee (at that time, *i. e.*, between 10th May and 5th June) of Manora head. This was during the hottest time of the year, and during the middle of the day, the heat there was almost unbearable. Consequently it is probable that the blocks were dried much too rapidly. In preparing them on a large scale, it will be easy to make them on the high ground, or on the flats, where such excessive heat will not be experienced, and to run them down by means of of a railway to the work.

(2). Such thorough mixing of the materials, on which in concrete so much depends, could not be attained in a few blocks made by hand as might be in a large quantity, for mixing which steam machinery would be used.*

(3). It being very desirable to begin the testing of the blocks during the monsoon of 1866, they were exposed in July, though even then they had not had nearly time enough to harden, the maximum age being† 77 days, the minimum 43, and the average $62\frac{7}{9}$ only; whereas, had time allowed, they would have been kept very much longer.

On the Alderney harbour works, it is considered that they are fit for use in three months after being made, but that it is better to give them a year or two.

(4). If used for the breakwater, the blocks will be deposited on smooth horizontal beds carefully prepared for them, very different from those on which the experimental blocks were placed.

(5). There will be very much less liability to shift, the weight of each block proposed to be used being 27 tons, whereas those experimented on weighed only $3\frac{3}{8}$ tons each. Moreover, instead of each block having alone to resist the force of the sea, all those used in the work will be built

* Good results might no doubt be attained by hand mixing under careful supervision, but in a large quantity of work this would be difficult.

† Time which elapsed between the mixing of the different blocks and exposure to S. W. monsoon ea.

| No. | | days. |
|---|---|---|
| 1 | .............................. | 69 |
| 2 | .............................. | 77 |
| 3 | .............................. | 74 |
| 4 | .............................. | 72 |
| 5 | .............................. | 59 |
| 6 | .............................. | 57 |
| 7 | .............................. | 55 |
| 8 | .............................. | 59 |
| 9 | .............................. | 43 |
| Average | .............................. | $62\frac{7}{9}$ |

together in a solid mass of such weight as to be quite beyond any danger of being moved by the sea, and moreover exposing comparatively a very small proportion of angles and arrises to injury.

It would seem, therefore, that the Portlandc ement blocks, containing the same proportions of cement as Nos. 1, 2, 5, 6 and 7, *i. e.*, 8 cubic feet in a total of 78 cubic feet of unmixed materials, or $10\frac{10}{39}$ per cent., may safely be used as now proposed, *i.e.*, in blocks weighing 27 tons each, and from 16 feet below to 8 feet above low water ordinary spring tides.

From the experiments explained in Part II., it would appear as if the hydraulic lime blocks should have stood much better then they did. The lime experimented on was from the same burning as that used for the blocks.

In the Part II. experiments, the proportions of sand to cement and hydraulic lime were 4 and 2 respectively. In Nos. 1, 2, 5, 6 and 7 blocks, the proportions of which would appear to be very suitable, sand was to cement as 2 to 1, and in No. 4 block, apparently the best of the two in which hydraulic lime was used, as $1\frac{1}{2}$ to 1. The proportion of hydiaulic lime could not however be increased without exceeding the cost of the cement blocks, as the Statement A. attached shows the rate for blocks similar to Nos. 1, 2, 5, 6 and 7 to be Rs. 0-5-6 per 1 cubic foot, and of hydraulic lime blocks like No. 4, Rs. 0-5-5, or only 1 pie per cubic foot less.

Considered, therefore, with reference to cost, the lime could not be used for the blocks in larger proportions as compared with the cement than was done in block No. 4.

Still it must be remembered that the experiments made with the blocks were very much on the safe side, and though they proved most fully that the materials and proportions adopted in those blocks which stood well might with great safety be adopted for the breakwater, yet they did not at all prove that those which failed, under the excessive tests to which they were exposed, must be unfit for the work. The experiments of which an account is given in Part II. and the way in which No. 4 block withstood the monsoon sea of 1866, are sufficient, I think, to make it appear likely that the hydraulic lime might with safety be used in the same proportions as in block No. 4 for the hearting, particularly if ample time is given for the concrete to harden before being exposed to a heavy sea. This however, as it has been shown that, at the rate

taken for cement, no saving can be expected from the use of lime, would only be in the event of the cement running short, or rising in price.

The experiments explained in Part II. show that the blocks may with advantage be immersed in still water, as soon as made, instead of leaving them exposed to the air. This however would be troublesome with blocks of the weight (27 tons) proposed to be used, and it will perhaps be found to be sufficient if arrangements are made to keep the blocks constantly damp.

It was observed that the hydraulic lime block No. 3, after it was taken out of the sea for examination after the S. W. monsoon of 1866, deteriorated much in quality, In the event of there being any probability of this lime being used above low water mark, it might therefore be well to make some experiments as to the effect upon it of alternate exposure to air and immersion in water.

The blocks for trial were made under the supervision of Mr. Humby, Sub-Engineer, and by him were all the arrangements for the lowering, raising, and examining them made. Under his superintendence also the moulds of pure cement tried after 2 years' exposure, and of which the results are given in Tables X., XI., and XII. of Part II., were made.

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## Part II.

The questions to be settled by these experiments were—

1st. Whether to use Portland Cement or Hydraulic Lime in the mortar for the blocks.

2nd. Whether to use shingle, lumps of conglomerate (mixed more or less with shingle), or broken stone, as the material for the bulk of the blocks.

3rd. Whether to use salt or fresh water in mixing the mortar.

4th. Whether to immerse the blocks in water, or to keep them in air, wetted from time to time.

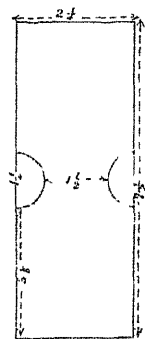
The question as to the quality of the sand to be used did not demand consideration, as there appeared to be every chance of sand of a most excellent quality, and very far superior to any procurable near Kurrachee, being obtained from native craft, bringing it as ballast from Mandavee, and this deposited close by the place where the blocks would be made, at a

rate hardly exceeding that at which very inferior sand from the Manora beach might be procured.

The experiments about to be explained were those carried out with a view to deciding questions 1, 3 and 4.

As there was good reason to believe that either Portland cement or the Kurrachee hydraulic lime would make good work,* the first question resolved itself mainly into one of comparative cost, and it was decided to determine it by testing the strength of mortar made of each, mixed with sand in such proportions as would give about the same cost.

Now the price of the Kurrachee Harbor Works hydraulic lime at Manora was calculated to be about 12 annas a cubic foot.† It was considered probable that Portland cement would be obtained at Manora for about double that price, as in estimate attached. Consequently, it was decided to try cement mixed with four times its bulk of sand against lime mixed with sand in the proportion of 1 to 2‡ only, so as to bring them to about the same price.

Before beginning the experiment, the Portland cement was tested, in order to obtain for the final trials a cask, the contents of which might be considered as of good average quality. Thirteen moulds were in August 1866 made of the shape and size shown opposite, and from as many different casks. Before taking the quantity required, the cement next to the edge of the cask was carefully mixed with that in the middle, so as to obtain a fair average. The cement was purchased in wooden casks at Kurrachee from Messrs. McIver & Co., and was not obtained from England specially for the purpose.

These specimens were prepared with salt water, of pure cement, and were, as soon as made, immersed in the sea from off the Kurrachee Harbor Works Dredge "Dubba," then lying alongside of the Napier Mole. Six days afterwards, the iron moulds in which they were

* We had then, 2½ years ago, upwards of 6 years' experience of the Kurrachee Harbor Works hydraulic lime, and there was reason to suppose that Portland cement would answer nearly, if not quite, as well as in England.

† In Mr. Price's paper on the Kurrachee Harbor Works hydraulic lime, published in the Roorkee Professional Papers of May 1867, the price was given as 10 annas per cubic foot. This, however, was on the supposition that it would be made at Kurrachee; the extra cost of firewood, fresh water, &c., at Manora would probably raise this to 12 annas.

‡ This is the proportion adopted for superstructure on the Harbor Works when using this hydraulic lime.

made were removed, and on the following day, *i. e.*, when the specimens were seven days old, they were tried, with results as below.

It was decided that we might reject all under 400 lbs. on $1\frac{1}{2}$-inch square. The average of those of greater strength, *i. e.*, Nos. 1, 2, 4, 12 and 13 gave 451 lbs., and for the later experiments, the nearest to that average (No. 2—445 lbs.) was adopted, in order to save mixing the five casks.

| Nos. | Broke with lbs. on $1\frac{1}{2}$-inch square. | Being per square in. lbs |
|---|---|---|
| 1 | 490 | $217\frac{7}{9}$ |
| 2 | 445 | $197\frac{7}{9}$ |
| 3 | 295 | $131\frac{1}{9}$ |
| 4 | 425 | $188\frac{8}{9}$ |
| 5 | 335 | $148\frac{8}{9}$ |
| 6 | $357\frac{1}{2}$ | $158\frac{8}{9}$ |
| 7 | 370 | $164\frac{4}{9}$ |
| 8 | 350 | $155\frac{5}{9}$ |
| 9 | 290 | $128\frac{8}{9}$ |
| 10 | 395 | $175\frac{5}{9}$ |
| 11 | $302\frac{1}{2}$ | $134\frac{4}{9}$ |
| 12 | 475 | $211\frac{1}{9}$ |
| 13 | 420 | $186\frac{2}{3}$ |
| Average .. .. | $380\frac{10}{13}$ | $169\frac{3}{13}$ |

In the following remarks, the letters C. L. S. F. W. and A. will be used to signify specimens composed of Cement or Lime,* mixed with Salt or Fresh water, and immersed in Water† or exposed to Air, respectively. Thus C. S. A. will mean a specimen composed of cement, mixed with salt water and exposed to air.

In every case, fresh water from the Rambagh well was used for slaking the lime and for mixing the lime and clay.

The sand used was from the bed of the Lyaree river, and was of tolerably good quality, though not to be compared with that from Mandavee, proposed to be used in the concrete blocks for the breakwater.

The machine used for testing the tensile strength was as shown on the accompanying drawing. It was similar to one used for the same purpose by the Engineer of the ballast board at Dublin.‡

By a slight alteration of arrangement, it has also, on the Kurrachee

* With their respective proportions of sand.

† The immersion was always in salt water.

‡ A Salter's balance, graduated sufficiently far, not being available, an ordinary scale was used.

Harbor Works, been made of use for trying the resistance of the specimens to a crushing force. The manner in which this was done is shown on the same drawing.

The hardness of the specimens was tried by means of an apparatus similar to the one described by Vicat in his work on "Limes and Cements."

By it, a steel point of a certain diameter, which is of course always maintained, is allowed to fall from a constant height on the specimen to be tried, the relative hardness of which is shown by the extent to which the point penetrates.

The results of the different trials are shown in the accompanying Tables.

Now, with reference to the first question to be decided, *i. e.*, whether Portland cement or the Kurrachee Harbor Works hydraulic lime should be adopted, there can be no doubt, inasmuch as the former is shown to be the best in every case except one (Table, No. IX.),* and there the superiority of lime appears to be but slight.

Then, as to the third question, whether to use salt or fresh water in mixing the mortar. Adding together the figures which show the strengths of specimens in the Tables, we find that, in tensile strength, salt water specimens are represented by a strength of $1,538\frac{1}{10}$ as compared with fresh water specimens shown by $1,359\frac{31}{60}$. The superiority of salt water does not appear to be so great with pure cement; in the seven days test of that material and pure lime, the extra strength is very slight, and in the pure cement tried after 25 months, the fresh water specimens are the best. In the two years tests though, of cement and lime mixed with sand, the superiority of salt water is very marked, and this test is the one on which we should most rely.

The hardness treated in the same way shows the penetration of salt water specimens to amount to 1·5645, where as that of fresh water specimens is only represented by 1·5400. This slight apparent superiority of fresh water (1·59 per cent. only) is however entirely the result of the seven days and four months trials. In both of the two years trials (pure cement and cement and lime mixed with sand) the salt water gives the best results. I consider therefore that the result is, on the whole, in favor of the use of salt water for mixing, as far as hardness is concerned.

* The superiority of the lime is, in this case, entirely due to the deficiency of one of the cement specimens, C. F. A., which gives so low a result compared with the others as to appear doubtful.

Then, as to power of resisting a crushing force, salt water is represented by 26,531$\frac{37}{63}$, and fresh water by 25,287$\frac{8}{21}$. The superiority of salt water appears most in the trials of cement and lime mixed with sand. In the case of the seven days test of pure cement, the difference is very trifling, and in the two years test of pure cement, fresh water proves to be much better. For the mixture with sand, however, the salt is undoubtedly the best, and therefore it seems that, whether with reference to tensile strength, hardness or power to resist crushing, salt water is better for mixing the materials than fresh.

This also was the result of experiments made by Mr. Smeaton and of a large number made by Mr. Grant, M. Inst. C. E., as explained by him in a paper on cement read before the Institution of Civil Engineers on the 12th December, 1865. It is, however, the reverse of the opinion expressed by General Gillmore, U. S. A., in his work on "Limes, Cements and Mortars." He however appears to refer to natural cements, not to the artificial Portland.

Then, as to the fourth question, whether to immerse the blocks when made, or to keep them in air, wetted from time to time. Taking the totals as before, the tensile strength of immersed specimens is represented by 922$\frac{3}{4}$ as compared with those exposed to air 711$\frac{8}{15}$,—as far as tensile strength is concerned, the immersed specimens are no doubt the best.

In the case of hardness though, the reverse is decidedly the conclusion at which we must arrive from these trials, the total penetration of specimens exposed to air being ·6559 as compared with 1·0978, representing immersed specimens.

This superior hardness of the air specimens was probably however very superficial. According to Vicat, the influence of the carbonic acid of the atmosphere in carbonising hydraulic lime does not extend after a year to more than six millimetres (·236 inch) from the surfaces exposed.

It would seem that, in addition to the hardening effect of exposure to air, the difference was in most cases increased by injury resulting at first from the action of the salt water on the immersed specimens. These specimens were made in their iron moulds on the bottom of the box* in which they were to be immersed; the box was after seven days raised to allow of the iron moulds being taken off, and again as soon as pos-

* This box, which was found to answer its purpose well, was composed of 1 inch pine plank, the bottom being strengthened longitudinally and transversely. Its outside dimensions were 5 feet 7 inches × 3 feet 8 inches × 7 inches.

sible put into the sea. Care was however taken not to move the specimens, and their lower surfaces were no doubt, being against the wood, much less exposed to the action of the water than the others were.

In trying the hardness of each specimen two tests were made of the top and two of the bottom side. Table No. XIV. shows that of 192 trials made of the hardness of immersed specimens, in 52 only, or $27\frac{1}{12}$ per cent., did the average hardness of the upper side exceed that of the surface in contact with the wood. 40 of these 52 specimens were of lime, and it would seem from the table that, as far as hardness is concerned, the Kurrachee Harbor Works hydraulic lime suffered at first less than Portland cement from the action of the water. In the two years' trials, the reverse however appeared to be the case.

All of the 52 specimens above-mentioned were mixed with salt water, and this strengthens the opinion already expressed, of its superiority for sub-marine work.

After seven days immersion, the average penetrations on the upper and lower surfaces were 0·″3333 and 0·″3016, respectively; after 4 months 0·″1660 and 0·″1462, respectively; after 2 years 0·″1222 and 0·″1146, respectively; and in the air specimens, the average penetrations after 4 months and 2 years were 0·″1012 and 0·″0652, respectively.

From this it appears that the average penetration of the air specimens after 2 years was 64·4 per cent. of that after 4 months. Of the immersed specimens tried on upper surface after 2 years was 73·6 per cent. of that after 4 months. On lower surface, 78·3 per cent. of that after 4 months.

It is evident, therefore, that the hardening of the immersed specimens was in progress, though not at so rapid a rate as in those exposed to air; also that it was going on faster in the case of the upper surface than in that of the lower, which was comparatively protected from the action of the water, and this shows I think that the generally less penetration on the lower surface was not owing to the probably greater density of that part of each specimen. Altogether it seems as before that at the age of

The top and bottom were connected by means of four iron bolts, one at each corner, having nuts at bottom and circular eyes at top, and to the latter chains were attached for slinging the box.

The sides, also of 1 inch pine, were attached to the top

45 holes, 1 inch in diameter, were made in the bottom, 45 in the top, 5 in each side, and 3 in each end, in all 106. These were intended to allow the sea water to flow in and out of the box

The moulds were prevented from shifting by means of strips of wood ¾-inch square, nailed between them to the bottom of the box.

two years all injury from the action of the water had ceased, and that a directly contrary effect was being experienced.

The Table (No. XIV.) shows that in the case of the pure lime and cement tried after seven days immersion there was the same difference between the penetrations of the upper and lower surfaces. This was much more the case in the cement than in the lime. It would seem as if there was an excess of lime, not only in the mortar made both with the cement and with the hydraulic lime, but also in those materials themselves; that this had been dissolved by the carbonic acid of the water and carried off, and that a contrary action had then set in, the same acid hardening the surfaces.

The large blocks for the breakwater, weighing 27 tons each, cannot without great extra labor be actually immersed as soon as made, but will be kept above high-water mark until ready for use, arrangements being made to keep them in the meantime constantly wet. In this manner it seems likely that they will benefit by the hardening properties of the carbonic acid both of the atmosphere and of the water. A series of experiments to prove whether, by delaying the immersion for some time, greater hardness could be attained without decreasing the tensile strength or power to resist crushing, would be valuable.

Then as regards power to resist crushing, specimens immersed in water are represented by $17,201\frac{5}{6}$; those exposed to air being shown by $13,013\frac{1}{3}$ only. It is evident that this test proves the former to be the best.

It would appear, therefore, that on the whole, the best result is likely to be obtained by immersion in water.

Between the ages of four months and two years the percentage of average improvement of the specimens was as shown in the accompanying Table. No. XV.

It was originally intended to test the power of resistance to oblique strain also, and with this view bricks were built out from the surface of a wall and at right angles to it, being attached by means of cement and lime, mixed with certain proportions of sand, as in the other tests.

It was however found that, in consequence of the experiment having been made too near the workshop chimney, the heat of which affected the trial, the result would not be satisfactory, and there being, when this was ascertained, none of the hydraulic lime available, this trial was abandoned.

The final results then of the experiments are as follows:—

Question 1st.—It is desirable to use Portland cement in preference to the Kurrachee Harbor Works hydraulic lime for the mortar of the blocks.

Question 3rd.—Salt water should be used in preference to fresh for mixing the mortar.

Question 4th —The blocks should, if easily practicable, be immersed in water as soon as made in preference to keeping them in air, wetted from time to time. The superiority of this course of action is, however, not so marked as to render it advisable to go to any great extra trouble to carry it out. It is possible that future experiments may show that immersion may be for a time delayed with advantage.

With reference to deciding the 2nd question, *i. e.*, whether to use shingle, lumps of conglomerate (mixed more or less with shingle), or broken stone, as the material for the bulk of the blocks, it has not been thought requisite to make any special experiments.

In some blocks which were made for trial, and which have been exposed during the last three monsoons to the full force of the sea, pieces of Manora conglomerate obtained close by were used, and these appear to have answered very well.* This being the case it seems quite unnecessary to think of bringing broken limestone from Ghizree, Hands' Hill, or elsewhere, many miles on the opposite side of the harbor. There can, I think, be no doubt that it will be well to use small lumps of conglomerate mixed with the shingle, so as to save the labor of breaking the shingle out of the conglomerate. Moreover the use of a certain proportion of conglomerate lumps will probably tend to bind the whole mass together more firmly, the fragments being always of a very jagged shape and affording an excellent "key," much better than can be expected from the smooth surfaces of the rolled shingle pebbles.

The artificial mortar to be used in the blocks could not be expected for a long time to take such a strong hold on the pebbles as the cementing material of the rock, which has been hardening for ages, has done, and it is this binding material which makes the lumps of conglomerate of such an uneven and desirable shape.

Some idea of the extent to which the Portland cement deteriorates on the passage from England may be obtained by a comparison of the

* Part I. of this Report contains an account of these experimental blocks.

results shown in these Tables with those given in the paper by Mr. Grant, already referred to.

The cement experimented on at Kurrachee weighed 102 lbs. per bushel. This weight is low compared with that referred to in Mr. Grant's paper, being the same as stipulated for in the contracts for the London southern main drainage works, in which provision was made for the supply of cement weighing not less than 110 ℔s. to the striked bushel. This was afterwards raised to 112 ℔s. per bushel. Mr. Grant gives the tensile strength of cement weighing 102 lbs. to the bushel mixed neat and immersed in water for seven days, as—

| | | | |
|---|---|---|---|
| Minimum ℔s. | $33\frac{1}{2}$ | per square inch | |
| Maximum „ | $179\frac{5}{9}$ | „ | „ „ |
| Average „ | $111\frac{8}{9}$ | „ | „ „ |

whereas, in similar experiments at Kurrachee, the results were—

| | |
|---|---|
| Minimum ... ℔s. | $128\frac{8}{9}$ |
| Maximum ... „ | $217\frac{7}{9}$ |
| Average ... „ | $169\frac{3}{13}$ |

It is evident, therefore, that the cement obtained at Kurrachee was considerably better than that of the same weight experimented on by Mr. Grant. It is not probable that the cement purchased here was, before exportation, of better quality than that tried on the main drainage works, and if this is admitted, these results confirm Mr. Grant's statement that it was ascertained by his tests that, "provided Portland cement be kept free from moisture, it did not, like Roman cement, lose its strength by being kept in casks or in sacks, but rather improved by age—a great advantage in the case of cement which had to be exported."

This appears to be still more the case after a greater exposure. Table No. IV. shows the average strength of the specimens of cement, mixed with four times its bulk of sand and immersed in water, to have been 129·25 ℔s. per square inch after being upwards of four months in the sea.

Mr. Grant gives the strength of cement weighing 112 ℔s. to the imperial bushel, and mixed with four times its bulk of sand, after six months, at 66·2, 69·7, 122·5 and 100·2 ℔s. per square inch, and after 12 months at 88·1, 98·5, 141·2 and 108·6 ℔s. per square inch, according as the sand was ordinary Thames, clean Thames, clean pit, or loamy pit.

Mr. Grant does not give the results of any experiments on the hardness of Portland cement; comparison in that respect cannot therefore be made, but with reference to power to resist crushing he gives very full

particulars. From these it seems that the cement experimented on at Kurrachee under that test also proved itself of good quality.

Though there can be no doubt of the superiority of the Portland cement as compared with the Kurrachee harbor works hydraulic lime, even when the former is mixed with four times, and the latter with only twice, its bulk of sand, yet, if the seven days tests are omitted (that being too short a time for the lime to gain strength to stand such a trial, though it sets sufficiently quickly under still water to allow of its use with success for concrete so deposited), it will be found that the lime did not, in the experiments referred to, give bad results.

It has been shown that its quality, with regard to tensile strength, hardness, and power of resistance to crushing, increased with age from four months to two years much more rapidly than that of the cement.

The moulds for trial (except those of pure cement tried after two years, the results of which are given in Tables X., XI. and XII., and which were made under Mr. Humby's superintendence) were prepared under the supervision of Mr. Bhumaya Seanna, Supervisor, 1st Grade, and he had charge of them till the time of trial. He was also of the greatest assistance to me in testing the strengths of the different specimens.

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ESTIMATE of probable cost of Portland cement at Manora.

| | RS. | A. | P. |
|---|---|---|---|
| Cost in England, 2*s.* 3*d.* per bushel, or $1\frac{1}{4}$ cubic foot, or, for 5 cubic feet, the quantity generally contained in each cask, ... | 4 | 8 | 0 |
| Freight at 45*s.* per ton of 50 cubic feet, on the supposition that 5 cubic feet of cement will occupy, with cask, &c., 6 cubic feet,* ... ... ... ... ... ... ... ... | 2 | 11 | $2\frac{2}{5}$ |
| Making, with prime cost, ... .. | 7 | 3 | $2\frac{2}{5}$ |
| Add for packing, shipping, landing and storing, to cover possible loss, and for contingencies 9·135 per cent. on prime cost and freight,* ... ... ... ... ... ... ... ... | 0 | 10 | $6\frac{1}{3}$ |
| Total probable cost of 5 cubic feet, ... ... | 7 | 13 | $8\frac{11}{15}$ |
| Or " " 1 " ... ... | 1 | 9 | $1\frac{56}{75}$ |
| Or, say per cubic foot, Rs. | 1 | 9 | 2 |

* The wooden casks, in which we have hitherto purchased the cement, would take up about $7\frac{1}{2}$ cubic feet each; but if iron cases, either rectangular or cylindrical, were used, the allowance above made would, I imagine, be found to be sufficient. These would preserve the cement better from damp than would the ordinary ones, and, though probably rather more expensive, they would be useful for many purposes on the works, whereas the wooden casks are generally nearly worn out when received.

## A.

### PROBABLE COST OF EXPERIMENTAL BLOCKS.*

| Materials and labor of mixing. | Rate. | Per. | Nos. 1, 2, 5, 6, and 7 Blocks | | Nos 8 and 9 Blocks. | | No 3 Hydraulic Lime Block. | | No. 4 Hydraulic Lime Block. | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Quantity. | Amount. | Quantity. | Amount. | Quantity. | Amount. | Quantity. | Amount | |
| | RS. A. P. | c. ft. | c. ft. | RS. A. P. | c. ft. | RS. A. P. | c. ft. | RS. A. P. | c. ft. | RS. A. P. | |
| Portland cement, ... | 1 9 2 | 1 | 8 | 12 9 4 | 12 | 18 14 0 | ... | ... | ... | ... | The Portland cement concrete blocks used for the breakwater at Alderney cost Rs. 0-3-10$\frac{2}{5}$ per cubic foot. |
| Hydraulic lime, ... | 0 12 0 | 1 | ... | ... | ... | ... | 8 | 6 0 0 | 16 | 12 0 0 | |
| Sand,† ... ... | 5 0 0 | 100 | 16 | 0 12 10 | 14 | 0 11 2 | 16 | 0 12 10 | 24 | 1 3 2 | |
| Shingle, ... ... | 4 0 0 | 100 | 54 | 2 2 7 | 54 | 2 2 7 | 54 | 2 2 7 | 50 | 2 0 0 | |
| | | c. yds. | | | | | | | | | |
| Water, ... ... | 0 0 3 | 2 | ... | 0 0 3 | ... | 0 0 3 | ... | 0 0 3 | ... | 0 0 3 | |
| Labor, ... ... | 3 0 0 | 2 | ... | 3 0 0 | ... | 3 0 0 | ... | 3 0 0 | ... | 3 0 0 | |
| Total for 2 cubic yards, ... | | ... | | 18 9 0 | | 24 12 0 | | 11 15 8 | | 18 3 5 | |
| " 1 " foot, ... | | ... | | 0 5 6 | | 0 7 4 | | 0 3 7 | | 0 5 5 | |

* The above does not give the actual cost, as this could not be justly ascertained in so small a number of blocks where so many incidental expenses were incurred. It is rather a table of comparative cost based on the rates of the different materials, and cost of labor, as far as they could be correctly judged of with reference to a large quantity of work.

† The sand from Mandavee would probably cost Rs 2-8-0 per 100 cubic feet only, but as it is not certain that all required can be obtained, the mean between that and the rate, Rs. 7-8-0, for sand from the river Lyaree is shown.

## No. I.—Tensile Strength.

Specimens of pure cement and pure hydraulic lime mixed with fresh and with salt water, immersed in the sea for seven days and then tried.

| Material tried and order of strength. | Age in months. | No. of trials. | Average broke per square inch lbs. | Remarks. |
|---|---|---|---|---|
| C. F. W. | $\frac{7}{30}$ | 1† | 300 | Total strength of cement specimens, ... ... ... $595\frac{5}{9}$ |
| C. S. W. | $\frac{7}{30}$ | 2 | $295\frac{5}{9}$ | ,, ,, lime ,, $84\frac{4}{9}$ |
| L. S. W. | $\frac{7}{30}$ | 2 | $48\frac{8}{9}$ | ,, ,, salt water ,, $344\frac{4}{9}$ |
| L. F. W. | $\frac{7}{30}$ | 2 | $35\frac{5}{9}$ | ,, ,, fresh ,, ,, $335\frac{5}{9}$ |

In this case it is evident that the cement was very superior to the lime, and that the specimens in which the materials were mixed with salt water were slightly better than those mixed with fresh.

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## No. II.—Hardness.

| Material tried and order of hardness. | Age in months. | No. of trials. | Average penetration in inches. | Remarks. |
|---|---|---|---|---|
| C. S. W. | $\frac{7}{30}$ | 8 | ·1208 | Total penetration of cement specimens, ... .. .. ·2583 |
| C. F. W. | $\frac{7}{30}$ | 8 | ·1375 | ,, ,, lime ,, 1·0114 |
| L. F. W. | $\frac{7}{30}$ | 16 | ·4927 | ,, ,, fresh water ,, ·6302 |
| L. S. W. | $\frac{7}{30}$ | 16 | ·5187 | ,, ,, fresh ,, ·6395 |

From these tests it is evident that the cement proved very much harder than the lime, and that the fresh water specimens were slightly harder than those mixed with salt water.

* The charge for packing, shipping, landing and storing a large quantity (of the value of Rs. 5,41,177) of plant and stores sent out from England for the Kurrachee Harbor Works, amounted to 2·135 per cent on prime cost and freight—2 per cent. is added to cover possible loss, that being the rate which would probably be paid if the cement was insured, though being for Government, this would of course not be done, and 5 per cent. is added for contingencies, making in all 9·135 per cent.

† A 2nd specimen of C. F. W. was tried, but it only gave $148\frac{8}{9}$ lbs. per square inch. This was so different from the other cement specimens that there must have been something wrong about it and it was ignored.

## No. III.—Resistance to Crushing.

| Material tried and order of strength. | Age in months. | No. of trials. | Average cracked at lbs. | Average crushed at lbs. | Remarks. | Cracked. | Crushed. |
|---|---|---|---|---|---|---|---|
| C. S. W. | $\frac{10}{30}$ to $\frac{11}{30}$ | 14 | $2{,}110\frac{5}{7}$ | $2{,}582\frac{1}{7}$ | Total strength of cement specimens | $4{,}423\frac{4}{7}$ | $5{,}147\frac{6}{7}$ |
| C. F. W. | $\frac{9}{30}$ to $\frac{13}{30}$ | 14 | $2{,}312\frac{6}{7}$ | $2{,}565\frac{5}{7}$ | Lime ,, | $587\frac{7}{9}$ | $894\frac{4}{9}$ |
| L. S. W. | $\frac{16}{30}$ | 9 | $272\frac{2}{9}$ | $451\frac{1}{9}$ | Salt water ,, | $2{,}382\frac{59}{63}$ | $3{,}033\frac{16}{63}$ |
| L. F. W. | $\frac{16}{30}$ | 9 | $315\frac{5}{9}$ | $443\frac{1}{2}$ | Fresh ,, ,, | $2{,}628\frac{26}{63}$ | $3{,}009\frac{1}{21}$ |

The figures here given as representing cracking and crushing weights are those which were required to crack and crush, respectively, cubes of $1\frac{1}{4}$ inch side.

From these it appears that the power of the lime to resist crushing was very small compared with that of Portland cement. That the specimens prepared with salt water were, as shown by the *crushing* weight, slightly stronger than those mixed with fresh, but that the *cracking* test showed the fresh water specimens to be comparatively a good deal stronger than the others.

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## No. IV.—Tensile Strength.

Specimens of Portland cement mixed with four times its bulk of sand compared with others composed of hydraulic lime mixed with twice its bulks of sand. The comparison being made with specimens mixed both with fresh and with salt water, and some being tried after being immersed in the sea for upwards of 4 months, and some after being exposed to the air for about the same time.

| Material tried and order of strength. | Age in months. | No. of trials. | Average broke per square inch lbs. | Remarks. | |
|---|---|---|---|---|---|
| C. S. W. | $4\frac{14}{30}$ | 6 | 141·5 | Total strength of cement specimens | 378·4 |
| C. F. W. | $4\frac{14}{30}$ | 6 | 117 | ,, lime ,, | 242·2 |
| L. F. W. | $4\frac{7}{30}$ | 6 | 83 | ,, salt water ,, | 318·4 |
| L. S. W. | $4\frac{7}{30}$ | 6 | 81·5 | ,, fresh ,, ,, | 302·2 |
| C. F. A. | $4\frac{8}{30}$ | 2 | 62·2 | ,, specimens immersed in water | 423·0 |
| C. S. A. | $4\frac{8}{30}$ | 4 | 57·7 | ,, specimens exposed to air | 197·6 |
| L. F. A. | $4\frac{8}{30}$ | 2 | 40 | | |
| L. S. A. | $4\frac{9}{30}$ | 4 | 37·7 | | |

Cement in this case appears to be considerably stronger than lime. The specimens prepared with salt water slightly better than those with fresh, and those immersed in water very much better than those exposed to air.

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## No. V.—Hardness.

| Material tried and order of hardness. | Age in months. | No. of trials. | Average penetration in inches. | Remarks. | | |
|---|---|---|---|---|---|---|
| C. F. A. | $4\frac{8}{30}$ | 8 | ·0813 | Total penetration of | cement specimens | ·4264 |
| C. S. A. | $4\frac{8}{30}$ | 16 | ·0875 | „ | lime „ | ·5884 |
| L. F. A. | $4\frac{8}{30}$ | 8 | ·0927 | „ | fresh water „ | ·4761 |
| C. S. W. | $4\frac{14}{30}$ | 24 | ·1263 | „ | salt „ „ | ·5387 |
| L. S. A. | $4\frac{8}{30}$ | 16 | ·1291 | „ | specimens exposed to air | ·3906 |
| C. F. W. | $4\frac{14}{30}$ | 24 | ·1313 | „ | specimens immersed in water | ·6242 |
| L. F. W. | $4\frac{7}{30}$ | 24 | ·1708 | | | |
| L. S. W. | $4\frac{7}{30}$ | 24 | ·1958 | | | |

Cement appears harder than lime. Fresh water rather better than salt, and immersion in water much inferior to exposure to air.

---

## No. VI.—Resistance to Crushing.

| Material tried and order of strength. | Age in months. | No. of trials. | Average cracked at lbs. | Average crushed at lbs. | Remarks. | | |
|---|---|---|---|---|---|---|---|
| L. S. W. | $4\frac{13}{30}$ | 6 | $2,111\frac{2}{3}$ | $2,333\frac{1}{3}$ | Total strength of | cement specimens, | $7,722\frac{1}{2}$ |
| C. S. W. | $4\frac{20}{30}$ | 5 | 2,094 | 2,200 | „ | lime „ | $6,043\frac{1}{3}$ |
| C. F. W. | $4\frac{20}{30}$ | 4 | $1,917\frac{1}{2}$ | $2,022\frac{1}{2}$ | „ | salt water „ | $7,578\frac{1}{3}$ |
| C. S. A. | $4\frac{17}{30}$ | 5 | 1,792 | 1,820 | „ | fresh water „ | $6,187\frac{1}{2}$ |
| C. F. A. | $4\frac{17}{30}$ | 2 | 1,575 | 1,680 | „ | specimens immersed in water, | $8,095\frac{5}{8}$ |
| L. F. W. | $4\frac{13}{30}$ | 4 | 1,540 | 1,540 | „ | specimens exposed to air, | 5,670 |
| L. S. A. | $4\frac{17}{30}$ | 4 | $1,102\frac{1}{2}$ | 1,225 | | | |
| L. F. A. | $4\frac{19}{37}$ | 4 | $927\frac{1}{2}$ | 945 | | | |

These figures, as well as those given in Tables IX. and XII., denote

the weights required to crack and crush, respectively, specimens $2\frac{3}{4}'' \times 2\frac{3}{4}'' \times 1\frac{1}{2}''$ set on the narrow side, *i. e.*, on a base $1\frac{1}{2}'' \times 2\frac{3}{4}''$.

Cement appears better than lime, salt water than fresh, and immersion in water much better than exposure to air.

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## No. VII.—Tensile Strength.

Specimens as before, but tried after being immersed in the sea or exposed to the air for upwards of two years.

| Material tried and order of strength. | Age in months. | No of trials. | Average broke per square inch, lbs. | Remarks. |
|---|---|---|---|---|
| C. S. A. | $24\frac{10}{30}$ | 1 | $228\frac{4}{5}$ | Total strength of cement specimens, $595\frac{23}{60}$ |
| C. S. W. | $24\frac{10}{30}$ | 2 | $155\frac{1}{2}$ | ,, lime ,, $418\frac{3}{10}$ |
| C. F. W. | $24\frac{10}{30}$ | 2 | $117\frac{3}{4}$ | ,, salt water ,, $599\frac{7}{10}$ |
| L. F. W. | $24\frac{10}{30}$ | 3 | $115\frac{1}{2}$ | ,, fresh ,, ,, $413\frac{59}{60}$ |
| L. S. W. | $24\frac{10}{30}$ | 3 | 111 | ,, specimens exposed to air, $513\frac{14}{15}$ |
| L. S. A. | $24\frac{10}{30}$ | 2 | $104\frac{2}{5}$ | ,, specimens immersed in water, $499\frac{3}{4}$ |
| C. F. A. | $24\frac{10}{30}$ | 1 | $93\frac{1}{3}$ | |
| L. F. A. | $24\frac{10}{30}$ | 3 | $87\frac{2}{5}$ | |

Cement appears to be better than lime, salt water than fresh, and exposure to air slightly better than immersion in water. This however is entirely due to one specimen only, C. S. A.

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## No. VIII.—Hardness.

| Material tried and order of hardness. | Age in months. | No. of trials. | Average penetration—in inches. | Remarks. |
|---|---|---|---|---|
| L. S. A. | $24\frac{11}{30}$ | 8 | ·0583 | Total penetration of cement specimens, ·3347 |
| C. S. A. | $24\frac{11}{30}$ | 4 | ·0625 | ,, lime ,, ·4042 |
| L. F. A. | $24\frac{11}{30}$ | 12 | ·0653 | ,, salt water ,, ·3471 |
| C. F. A. | $24\frac{11}{30}$ | 4 | ·0792 | ,, fresh ,, ,, ·3918 |
| C. S. W. | $24\frac{10}{30}$ | 12 | $\cdot 088\dot{8}$ | ,, specimens exposed to air, ·2653 |
| C. F. W. | $24\frac{10}{30}$ | 12 | ·1042 | ,, specimens immersed in water, ·4736 |
| L. S. W. | $24\frac{10}{30}$ | 12 | ·1375 | |
| L. F. W. | $24\frac{10}{30}$ | 12 | ·1431 | |

Cement seems to be better than lime, salt water rather better than fresh, and exposure to air very much superior to immersion in water.

## No. IX.—Resistance to Crushing.

| Material tried and order of strength. | Age in months. | No. of trials | Average cracked at lbs. | Average crushed at lbs. | Remarks. |
|---|---|---|---|---|---|
| C. S. W. | $24\frac{12}{30}$ | 3 | 2,271 | 2621 | Total strength of lime specimens, $8,378\frac{1}{3}$ |
| C. S. A. | $24\frac{11}{30}$ | 1 | 2,250 | 2320 | " cement " 8,071 |
| L. S. W. | $24\frac{12}{30}$ | 2 | 2,035 | 2265 | " salt water " 9,456 |
| L. S. A. | $24\frac{13}{30}$ | 2 | 1,705 | 2250 | " fresh " " $6,993\frac{1}{3}$ |
| L. F. W. | $24\frac{12}{30}$ | 3 | $2\,093\frac{1}{3}$ | 2210 | " specimens immersed in water, 9,106 |
| C. F. W. | $24\frac{12}{30}$ | 3 | $1,883\frac{1}{3}$ | 2010 | " specimens exposed to air, $7,343\frac{1}{3}$ |
| L. F. A. | $24\frac{13}{30}$ | 3 | $1,606\frac{2}{3}$ | $1653\frac{1}{3}$ | |
| C. F. A. | $24\frac{13}{30}$ | 1 | 1,120 | 1120 | |

Lime appears better than cement, salt water very much better than fresh, and immersion in water better than exposure to air.

## No. X.—Tensile Strength.

Specimens of pure Portland cement mixed some with fresh and some with salt water, and exposed to air for more than two years.

| Material tried and order of strength. | Age—in months. | No of trials. | Average broke per square inch—lbs. | Remarks. |
|---|---|---|---|---|
| C. F. A. | $25\frac{14}{30}$ to 25 | 8 | $307\frac{7}{9}$ | |
| C. S. A. | $25\frac{14}{30}$ to 25 | 4 | $275\frac{5}{9}$ | |

By these trials fresh water is shown to be better than salt.

## No. XI.—Hardness.

| Material tried and order of hardness. | Age—in months. | No. of trials. | Average penetration—in inches. | Remarks. |
|---|---|---|---|---|
| C. S. A. | $25\frac{3}{30}$ to $25\frac{17}{30}$ | 24 | ·0392 | |
| C. F. A. | " to " | 36 | ·0419 | |

In these cases salt water appears to be better than fresh.

## No. XII.—Resistance to Crushing.

| Material tried and order of strength. | Age—in months. | No. of trials. | Average cracked at lbs. | Average crushed at lbs. | Remarks. |
|---|---|---|---|---|---|
| C. F. A. | $25\frac{3}{30}$ to $25\frac{28}{30}$ | 4 | $7,667\frac{1}{2}$ | $9,097\frac{1}{2}$ | |
| C.S. A. | $25\frac{14}{30}$ to $25\frac{23}{30}$ | 5 | 5,656 | 6,464 | |

From these tests fresh water appears better, by far, than salt.

One specimen (fresh water) cracked at 11,490 lbs.; at 12,490 lbs., the machine broke. This specimen and five others, also mixed with fresh

water, were not crushed, it being thought unnecessary to strain the machine in doing it, when the superiority of the cement mixed with fresh water was evident.

In order to judge of the adhesiveness of the cement and lime, slabs of Hand's Hill limestone, each 1 foot square and about 3½ inches thick, were dressed, the faces being made very smooth, and each pair joined with—

1st—Portland cement—pure.

2nd.—Ditto ditto with 4 parts by measure of—sand.

3rd.—Kurrachee harbor works hydraulic lime—pure.

4th.—Ditto ditto with 2 parts by measure of sand. Salt water being used in mixing, and sand from the Lyaree river.

These after some days were suspended by means of nippers, and weights were applied in the same way to lower stones. The results were as follows:—

No. XIII.

| Material experimented on, order of adhesiveness. | Age of mortar joint, days. | Weight per square inch which tore the stones apart, lbs. | Remarks. |
|---|---|---|---|
| Portland cement—pure, .. .. | 18 | 14·847 | The break was half from the top stone and half from the lower, the cement itself breaking across diagonally. |
| Hydraulic lime with 2 measures of sand, .. .. | 17 | 11·470 | The mortar broke through itself over about one-third of the surface, and separated from the stones over the remainder. |
| Portland cement with 4 measures of sand, .. .. | 17 | 11·416 | The cement separated quite clear from the top stone. |
| Hydraulic lime—pure, .. .. | 17 | 9·460 | Great difficulty was experienced in making this trial in consequence of the stones constantly giving way. The mortar finally separated from the stones, leaving about one half on either side. This resulted after 20 days from a strain of 7·326 lbs. per square inch, much less than it had previously withstood. The greatest resistance 9·46 lbs. is therefore given in the Table, the deterioration having probably resulted from the excessive shaking and knocking about which the specimen underwent in the interval. |

### No. IX.—Resistance to Crushing.

| Material tried and order of strength | Age in months. | No. of trials | Average cracked at lbs. | Average crushed at lbs. | Remarks. |
|---|---|---|---|---|---|
| C. S. W. | $24\frac{12}{30}$ | 3 | 2,271 | 2621 | Total strength of lime specimens, 8,378⅓ |
| C. S. A. | $24\frac{13}{30}$ | 1 | 2,250 | 2320 | „ cement „ 8,071 |
| L. S. W. | $24\frac{12}{30}$ | 2 | 2,035 | 2265 | „ salt water „ 9,456 |
| L. S. A. | $24\frac{11}{30}$ | 2 | 1,705 | 2250 | „ fresh „ „ 6,993⅓ |
| L. F. W. | $24\frac{12}{30}$ | 3 | 2,093⅓ | 2210 | „ specimens immersed in water, 9,106 |
| C. F. W. | $24\frac{12}{30}$ | 3 | 1,883⅓ | 2010 | „ specimens exposed to air, 7,343⅓ |
| L. F. A. | $24\frac{13}{30}$ | 3 | 1,606⅔ | 1653⅓ | |
| C. F. A. | $24\frac{13}{30}$ | 1 | 1,120 | 1120 | |

Lime appears better than cement, salt water very much better than fresh, and immersion in water better than exposure to air.

### No. X.—Tensile Strength.

Specimens of pure Portland cement mixed some with fresh and some with salt water, and exposed to air for more than two years.

| Material tried and order of strength. | Age—in months. | No of trials. | Average broke per square inch—lbs. | Remarks. |
|---|---|---|---|---|
| C. F. A. | $25\frac{14}{30}$ to 25 | 8 | $307\frac{7}{9}$ | |
| C. S. A. | $25\frac{14}{30}$ to 25 | 4 | $275\frac{5}{9}$ | |

By these trials fresh water is shown to be better than salt.

### No. XI.—Hardness.

| Material tried and order of hardness. | Age—in months. | No. of trials. | Average penetration—in inches. | Remarks. |
|---|---|---|---|---|
| C. S. A. | $25\frac{3}{30}$ to $25\frac{17}{30}$ | 24 | ·0392 | |
| C. F. A. | „ to „ | 36 | ·0419 | |

In these cases salt water appears to be better than fresh.

### No. XII.—Resistance to Crushing.

| Material tried and order of strength. | Age—in months. | No. of trials. | Average cracked at lbs. | Average crushed at lbs. | Remarks. |
|---|---|---|---|---|---|
| C. F. A. | $25\frac{7}{30}$ to $25\frac{29}{30}$ | 4 | 7,667½ | 9,097½ | |
| C. S. A. | $25\frac{14}{30}$ to $25\frac{28}{30}$ | 5 | 5,656 | 6,461 | |

From these tests fresh water appears better, by far, than salt.

One specimen (fresh water) cracked at 11,490 lbs.; at 12,490 lbs., the machine broke. This specimen and five others, also mixed with fresh

water, were not crushed, it being thought unnecessary to strain the machine in doing it, when the superiority of the cement mixed with fresh water was evident.

In order to judge of the adhesiveness of the cement and lime, slabs of Hand's Hill limestone, each 1 foot square and about 3½ inches thick, were dressed, the faces being made very smooth, and each pair joined with—

1st—Portland cement—pure.

2nd.—Ditto ditto with 4 parts by measure of—sand.

3rd.—Kurrachee harbor works hydraulic lime—pure.

4th.—Ditto ditto with 2 parts by measure of sand. Salt water being used in mixing, and sand from the Lyaree river.

These after some days were suspended by means of nippers, and weights were applied in the same way to lower stones. The results were as follows:—

No. XIII.

| Material experimented on, order of adhesiveness. | Age of mortar joint, days. | Weight per square inch which tore the stones apart, lbs. | Remarks. |
|---|---|---|---|
| Portland cement—pure, .. .. | 18 | 14·847 | The break was half from the top stone and half from the lower, the cement itself breaking across diagonally. |
| Hydraulic lime with 2 measures of sand, .. .. | 17 | 11·470 | The mortar broke through itself over about one-third of the surface, and separated from the stones over the remainder. |
| Portland cement with 4 measures of sand, .. .. | 17 | 11·416 | The cement separated quite clear from the top stone. |
| Hydraulic lime—pure, .. .. | 17 | 9·460 | Great difficulty was experienced in making this trial in consequence of the stones constantly giving way. The mortar finally separated from the stones, leaving about one half on either side. This resulted after 20 days from a strain of 7·326 lbs. per square inch, much less than it had previously withstood. The greatest resistance 9·46 lbs. is therefore given in the Table, the deterioration having probably resulted from the excessive shaking and knocking about which the specimen underwent in the interval. |

From this it appears that the pure cement is, with reference to adhesiveness, greatly superior to pure Kurrachee Harbor Works hydraulic lime, but that the hydraulic lime mixed with two measures of sand is, though very slightly, better than the cement mixed with four measure of sand.

The latter is the trial of greatest importance in the experiments under report.

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## No. XIV.

Showing the difference in the immersed specimens between the hardness of surfaces in contact with wood and exposed fully to the action of the sea water.

| Material tried. | Age in months | No. of trials. | Average penetration. | | Proportions of sand used. | Average penetration of | | F. and S specimens taken together average penetration of top exceeds by inches |
|---|---|---|---|---|---|---|---|---|
| | | | Top inches | Bottom inches. | | Top exceeds by inches | Bottom exceeds by inches. | |
| C. F. W. | $\frac{7}{30}$ | 8 | ·1708 | ·1042 | Cement and lime used pure, | ·0666 | ...... | $\frac{\cdot1083}{2}$ |
| C. S. W. | $\frac{7}{30}$ | 8 | ·1417 | ·1000 | | ·0417 | ...... | |
| L. F. W. | $\frac{7}{30}$ | 16 | ·5083 | ·4771 | | ·0312 | ...... | $\frac{\cdot0187}{2}$ |
| L. S. W. | $\frac{7}{30}$ | 16 | ·5125 | ·5250 | | ...... | ·0125 | |
| C. F. W. | $4\frac{14}{30}$ | 24 | ·1417 | ·1208 | Cement and lime mixed with 4 and 2 measures of sand respectively, | ·0209 | ...... | $\frac{\cdot0459}{2}$ |
| C. S. W. | $4\frac{14}{30}$ | 24 | ·1389 | ·1139 | | ·0250 | ...... | |
| L. F. W. | $4\frac{7}{30}$ | 24 | ·1917 | ·1500 | | ·0417 | ...... | $\frac{\cdot0334}{2}$ |
| L. S. W. | $4\frac{7}{30}$ | 21 | ·1917 | ·2000 | | ...... | ·0083 | |
| C. F. W. | $24\frac{10}{30}$ | 12 | ·1139 | ·0945 | | ·0194 | ...... | $\frac{\cdot0082}{2}$ |
| C. S. W. | $24\frac{10}{30}$ | 12 | ·0833 | ·0945 | | ...... | ·0112 | |
| L. F. W. | $24\frac{10}{30}$ | 12 | ·1500 | ·1361 | | ·0139 | ...... | $\frac{\cdot0223}{8}$ |
| L. S. W. | $24\frac{10}{30}$ | 12 | ·1417 | ·1333 | | ·0084 | ...... | |
| Total, ... | | | 2·4862 | 2·2494 | | ·2688 | ·0320 | $\frac{\cdot2368}{2}$ |

Note.—In Cement specimens, the total of the average penetrations at top exceeds that at bottom by, .................................. 0·1624 inch.
In hydraulic lime „ „ „ 0·0744 „
In specimens mixed with salt water „ 0·0431 „
„ „ fresh „ „ 0·1937 „

## No. XV.

TABLE showing the percentage of improvement of the specimens between the age of 4 months and 2 years.

| | Tensile strength. | Hardness. | Power to resist crushing. |
|---|---|---|---|
| Portland cement, .. .. .. .. .. | 57·41 | 21·04 | 4·52 |
| Hydraulic lime, .. .. .. .. .. | 72 73 | 31·31 | 38·64 |
| Mixed with salt water, .. .. .. .. | 88·68 | 35 57 | 24·78 |
| " fresh water, .. .. .. .. | 37·09 | 17·71 | 13·01 |
| Exposed to air, .. .. .. .. .. | 159·09 | 32·08 | 29·51 |
| Immersed in water, .. .. .. .. | 18·20 | 24·13 | 12·48 |
| Totals, .. | 433 20 | 161·84 | 122·94 |

From this Table it appears that the lime improved in every respect much more rapidly than the cement; the specimens mixed with salt water than those with fresh, and the specimens exposed to air much more so than those immersed in water.

Also that there was a much greater improvement in tensile strength than in hardness, except in the case of specimens immersed in water, and that the increase in hardness was altogether about 24 per cent. greater than in power to resist crushing; the hydraulic lime being an exception, and showing a greater improvement on the side of the power to resist crushing.

KURRACHEE
HARBOUR WORKS' OFFICE,
*29th March*, 1869.

C. M.

# No. IIIA.

## ARTESIAN WELL SINKING AT UMBALLAH.

By Captain Charles Branson, 37*th N. I., Senior Department, Thomason C. E. College.*

Artesian wells are of very ancient origin, and constantly used by the Chinese and Japanese. They derive their name, however, from the place in France where they are practised, viz., Artois.

The most remarkable instance of Artesian well existing is that at Grenelle, which is 1800 feet deep, and took six years to bore.

The object aimed at by this description of well is to bore down through impervious strata, that do not contain water, into lower strata fully charged with it, the water rising by hydrostatic pressure.

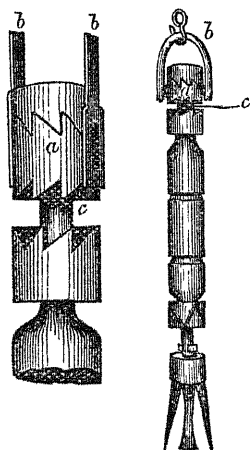
Till the invention of the machine set up at Umballa, the boring was done by hand, a stage being built for the workmen to stand on, having a crab or windlass on it for hoisting and lowering the rods.

As may be imagined, hand boring was expensive and tedious in its operations. Tubes of iron were sunk in the hole made by the auger or boring tool, and when one of a certain size, say the full size then used, viz., $2\frac{1}{2}$ to 3 inches, could not be moved any further, as, for instance, when it met with hard rock, a smaller borer was used to bore its way beyond this point, and as it progressed, tubes of the next smallest size were lowered through the upper and larger ones.

The steam machine, however, has entirely superseded the hand boring one. By its means the boring is more rapidly and economically done; the hole is very much larger, being 10 to 12 inches at the top, and there is less waste of time and less chance of failure than with the latter.

The principle naturally is the same in each case; the only difference being in the boring, which is managed by a very ingenious contrivance shown on the next page. The centre piece marked *a* is attached to

the hoop *b*, and slides easily up and down the spindle *c*. It has its upper and under edges formed into teeth, each tooth being formed by a perpendicular and inclined line.

The teeth of the lower edge are in the opposite direction to those of the upper. When the borer is hoisted, the upper teeth catch those at the head of the borer, and cause the borer to rotate slightly. When the borer is lowered, the lower teeth catch those at the lower part of the spindle, and thus a circular motion is given. The band is made broad so that it does not uncoil, but recovers its original position each time the borer is lowered. A further account of the borer is given further on.

*Elevation of Borer.*

There are two small and one large cylinders belonging to the machine. The two small ones drive the big drum on which the band (formed of six strong hemp ropes side by side) for the borers is coiled. The big cylinder is used for raising and lowering the borers. It is different from the usual style of cylinder, inasmuch as the steam is always sent into it below, and never above, the piston. On the top of the piston rod of this cylinder, is a heavy head, carrying a broad grooved wheel, over which the rope band above-mentioned passes. The piston rod is square not round.

The mode of working is extremely simple; the steam is first let into the small cylinder which drives the big drum. A borer having been previously hooked on to the band, the big drum is made to revolve and pay out sufficient rope to let the borer down the well to the bottom. The steam is then cut off from the small cylinder, and the back part of the band being clamped to the standard by a short screw and plate, the steam is passed into the big cylinder which drives the piston vertically up and down, thus lifting the rope band which passes over the small drum at the piston head; one portion being clamped, the other is naturally hauled up and let down, by the upward and downward motion of the piston rod.

*Figs.* 1 and 2, *Plate* VII., shows the working of this part of the machine. One of the standards or uprights is supposed to be removed;

the dotted lines represent the position when the piston is down, and therefore the boring end of the band lowered.

As the borer gets through the ground and arrives at the full length first clamped, the band is unclamped and a couple of inches more paid out and again clamped, and so on till the borer has gone some little depth, when the band is again unclamped, the steam cut off from the big cylinder and admitted into the two small ones, which, by driving the big drum in the opposite direction to that first driven, winds up the band and brings the borer to the surface.

As before stated, the steam is only admitted below the piston in the big cylinder for the simple reason that it would be unnecessary above it, since the weight of the heavy head of the piston rod, together with that of the boring irons attached to the band passing over the pulley at its head are quite sufficient, in fact far more than sufficient, to drag the piston down again. When the piston, therefore, is raised its full height, the steam below is allowed to pass out by a waste steam pipe, the working of which will be described further on. If no means were adopted to stop the descent of the piston it would descend with sufficient force to drive out the bottom of the cylinder and destroy the whole machine; to prevent this there is a small steam pipe at the bottom of the cylinder which always remains open while the cylinder is at work. This small pipe keeps up a constant but small supply of steam below the piston. The escape steam valve is 3 or 4 inches above the bottom of the cylinder, and immediately opposite the steam port; the piston, while descending, forces the waste steam together with that issuing out of the small steam tube below, through the escape tube, till it reaches the lower edge of the escape valve, when it naturally cuts off the egress of the supply steam which is still entering by the small tube, and compresses it, but is prevented, by means of this simple but powerful cushion of steam, from coming in contact with the bottom of the cylinder.

The valves in the steam and escape ports are worked by means of square rods, having pallets on them placed at an angle to the horizon. These pallets and rods somewhat resemble the escapement of a clock both in appearance and mode of working. They give an oscillating motion to the rods which open and shut the valves below. The engineer in charge called these pallets "tappets," and by that name, therefore, they will be called in future when referring to them.

*Plate* VIII. will explain the construction of the tappet rods, tappets and valves. These tappets are struck each time the piston head passes them, and being inclined planes, either the piston head must move out of the way, or they must move out of the way of the piston head; the tappet rods are therefore supported by brackets in which they freely rotate, and, by their backward sand forward motion, open and close the valves as before-mentioned.

The small cylinder and machinery below for working the drum are of the usual description, it is, therefore, unnecessary to give an account of them.

*Figs.* 1, 2, 3, *Plate* IX., illustrate the mode adopted for fastening the various tools required for the borer, also the way the loop is formed in the rope band.

The slanting grooves noticed in the portion of the borer just above the place where the chisels are fixed, were originally intended to assist in cutting the sides of the hole when going through clay: they are cut in opposite directions so as to work both ways; I understand, however, that they are not now used.

When the borer has worked its way down a short distance, it is hoisted and unhooked. A pump is then hooked on and lowered into the hole. This pump acts somewhat on the principle of the sand-pump, but has no separate sand box.

*Figs.* 4 and 5, *Plate* IX., are longitudinal sections of the pump of which the following is a description. The pump consists of a hollow tube of iron, having, at its upper end, a strong curved hoop attached. In the centre of this hoop, is a strong collar, through which the clack valve rod passes, which will be explained further on. The bottom of the pump tube has its inner edge chamfered for the seating of the clack valve hoop. The tube is open at both ends.

The piston has not a centre rod as in ordinary pumps, but is precisely similar to the piston used in the patent coffee-pot, which requires a small winding apparatus to haul it up. I can think of no other way of describing it, but the figures will perfectly illustrate my meaning. The hook at the end of the rope band is hooked on to the upper or curved part of the piston rod; the big cylinder being then forked, hauls the piston up; when released, the vacuum formed below the piston causes it to descend. Any fluid in the pump rushes through the valve in the piston, and on the

piston being again raised, the fluid is pumped out at the top and the clay or sand sucked into the lower part of the tube.

The valve of the piston consists of a strong circular disc of india rubber, which moves up and down the spindle at the bottom of the piston rods, joining the piston rods to the piston. It is prevented going too high by a flat circular flange cast on the spindle. The centre of the spindle and piston are bored out truly cylindrical, and through them the clack valve rod works. The india rubber disc valve is seated half its thickness in the piston, the upper surface of which is cut out for that purpose. On the top of the india rubber disc, is fastened a heavy iron one, which keeps the centre of the valve rigid, and saves it from the wear that would take place if it were allowed to strike the flange above.

The clack valve is of the ordinary description, working upwards, *i. e.*, into the pump tube. The valve is seated on a strong hoop or disc, which has a strong vertical hoop over the valve, like the guides of a ball and socket valve. This vertical hoop is attached to the clack rod which passes up the whole length of the pump, and projects 3 or 4 inches beyond the spindle. Just where it emerges from the latter, it has a hole bored through it, into which a key fits, and at the upper extremity it is furnished with a screw and nut.

When the pump is being used, the clack rod is hauled up and keyed, thus bringing the clack valve hoop and seating into the pump tube, and pressing it into the chamfer. When the pump has become nearly filled, it is hauled up, and the key being knocked out, the clack rod is lowered the distance between the key hole and nut (3 to 4 inches), thus leaving room, below the pump tube and between it and the clack valve, for extracting the clay or other material inside the pump.

The greatest distance bored by this machine, in easy soil, in one day, was 14 feet; sometimes, in hard strata, such as rock, scarcely a couple of inches can be bored. The average depth bored, however, per diem, is stated to be 8 or 9 feet. The tubes used to line the well are of cast-iron, and are driven by this machine precisely as by an ordinary pile driving engine.

I was unable to gain any information regarding the cost of the Umballah well, which has now reached a depth of 200 feet.

C. B.